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CONTRIBUTIONS TO OCEANOGRAPHY AND FISHERIES BIOLOGY
BYDRAES TOT OSEANOGRAFIE EN VISSERYBIOLOGIE

CAPE TOWN KAAPSTAD

1981

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Published in 1981 by the Sea Fisheries Institute, Private Bag X2, Rogge Bay 8012

In 1981 deur die Instituut Seevisserye, Privaatsak X2, Roggebaai 8012, uitgegee

Fisheries Bulletin South Africa
15
Visserye-Bulletin Suid-Afrika

ISBN 0 621 06271 5

Edited by/Geredigeer deur
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Printed for the Government Printer, Pretoria,
by
Galvin & Sales (Pty) Ltd, Cape Town

Gedruk vir die Staatsdrukker, Pretoria,
deur
Galvin & Sales (Edms) Bpk, Kaapstad

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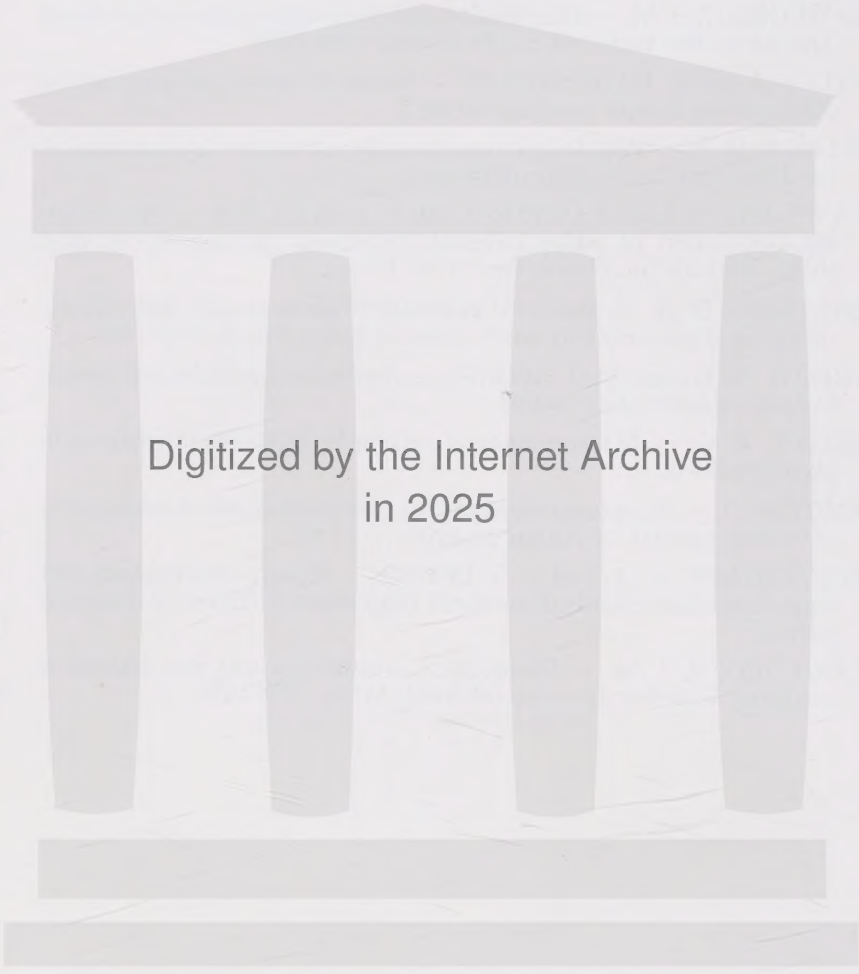

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Fish. Bull. S. Afr. 15:1–41
1981

DISTRIBUTION AND AVAILABILITY OF HORSE MACKEREL *TRACHURUS TRACHURUS* OFF SOUTH AFRICA, 1964-1976

R. J. M. CRAWFORD

Catches of horse mackerel *Trachurus trachurus* by South African purse-seiners have seldom been recorded north of latitude 30°S or east of Quoin Point, further evidence that two separate stocks of this species exist in South African waters: one situated off the Western Cape and the other off the South-East Coast. Annual purse-seine landings from the Western Cape stock averaged about 80 000 tons between 1950 and 1958, when two strong year-classes dominated the fishery, and approximately 40 000 tons from 1959 to 1966. Much smaller yields were recorded subsequently, a trend likely to have been influenced by the introduction of a small-meshed net in 1966, leading to increased fishing mortality of young age groups. The Western Cape stock is made up of three distinct age components: nought-year-olds recruit to the fishery during winter, being especially abundant between Lambert's Bay and St Helena Bay; fish aged one and two generally occur between Lambert's Bay and Quoin Point, are most available at the beginning of the year, and probably move off shore as the season progresses; adults are caught from time summer through midwinter on the northern fishing grounds, where their inshore presence is thought to be related to food availability.

Nog 'n stawende bewys van twee aparte stapels van marsbanker *Trachurus trachurus* in die Suid-Afrikaanse waters is dat vangste deur Suid-Afrikaanse beursnetbote selde noord van breedtegraad 30°S of oos van Quoinpunt aangeteken word. Die een stapel is geleë langs die Weskaap en die ander teenoor die Suidooskus. Gedurende 1950 tot 1958 toe twee sterk jaarklasse die vissery oorheers het, was die jaarlikse vangste van die Weskaapse beursnetbote gemiddeld 80 000 ton en ongeveer 40 000 ton van 1959 tot 1966. Daarna is heelwat kleiner opbrengste aangeteken, 'n neiging wat waarskynlik aangehelp is deur die ingebruikstelling van 'n kleinmaasnet gedurende 1966 en die daaropvolgende toename in die bevissingsmortaliteit van die jong ouderdomsgroepe. Die Weskaapse stapel bestaan uit drie duidelike ouderdomskomponente: nul jaar oue visse wat in die winter tot die vissery rekruteer en veral tussen Lambertsbaai en St Helenabaai volop is; vis een en twee jaar oud kom gewoonlik voor tussen Lambertsbaai en Quoinpunt, waar hul beskikbaarheid aan die begin van die jaar 'n hoogtepunt bereik en namate die seisoen vorder, beweeg hulle waarskynlik na aflandige waters; geslagsryp vis wat van laat somer tot die middel van die winter in die noordelike visgronde gevang word waar hulle aanlandige teenwoordigheid vermoedelik verband hou met voedselbeskikbaarheid.

On the basis of differences in catch-per-unit-effort trends (De Villiers 1977) backed up by biological evidence (Draganik 1977), it is now recognized that two separate stocks of horse mackerel *Trachurus trachurus* are present in South African waters. The one is found in Divisions 1.5 and 1.6 of the International Commission for the Southeast Atlantic Fisheries (ICSEAF) and the other in Divisions 2.1 and 2.2 (Fig. 1). In addition, a third is located off the South West African coast (Divisions 1.3 and 1.4). These three populations belong to the Cape sub-species *T. t. capensis* (Cast.), as recognized by the ICSEAF Working Group on Demersal Species at their first meeting (Madrid, May 1973), whereas Angolan catches often include *T. t. trecae* (Cadenat) the Cunene horse mackerel (Draganik *op. cit.*). The former may be distinguished by the longer length of the secondary (dorsal) lateral line, which ends at the posterior edge of the second dorsal fin. By contrast, that of the Cunene form terminates near the middle of the base of the first dorsal fin.

Horse mackerel contribute both to the South African demersal and purse-seine landings. The annual demersal landings of horse mackerel from the various ICSEAF divisions are updated in Table I from the information given by De Villiers (1977). The total demersal catch from all Divisions increased from 445 metric tons in 1950 to 11 661 tons in 1976, largely as a result of increased fishing east of Cape Agulhas after 1965. However, it is with the purse-seine fishery of Divisions 1.5 and 1.6 and in particular with the distribution of, and seasonal changes in, the availability of the horse-mackerel population in the same Divisions after 1964 that this report is primarily concerned.

Under the stimulus of a war-time demand for canned food, commercial purse-seine fishing for horse mackerel and pilchard *Sardinops ocellata* was initiated in the area of St Helena Bay (Fig. 1) in 1943. Although no accurate records were kept prior to 1950, Du Plessis (1959) estimated that, between 1943 and 1949, the annual landings of the two species increased from about 6 500 tons to approximately 113 000 tons. Of the latter total, horse mackerel was thought to account for some

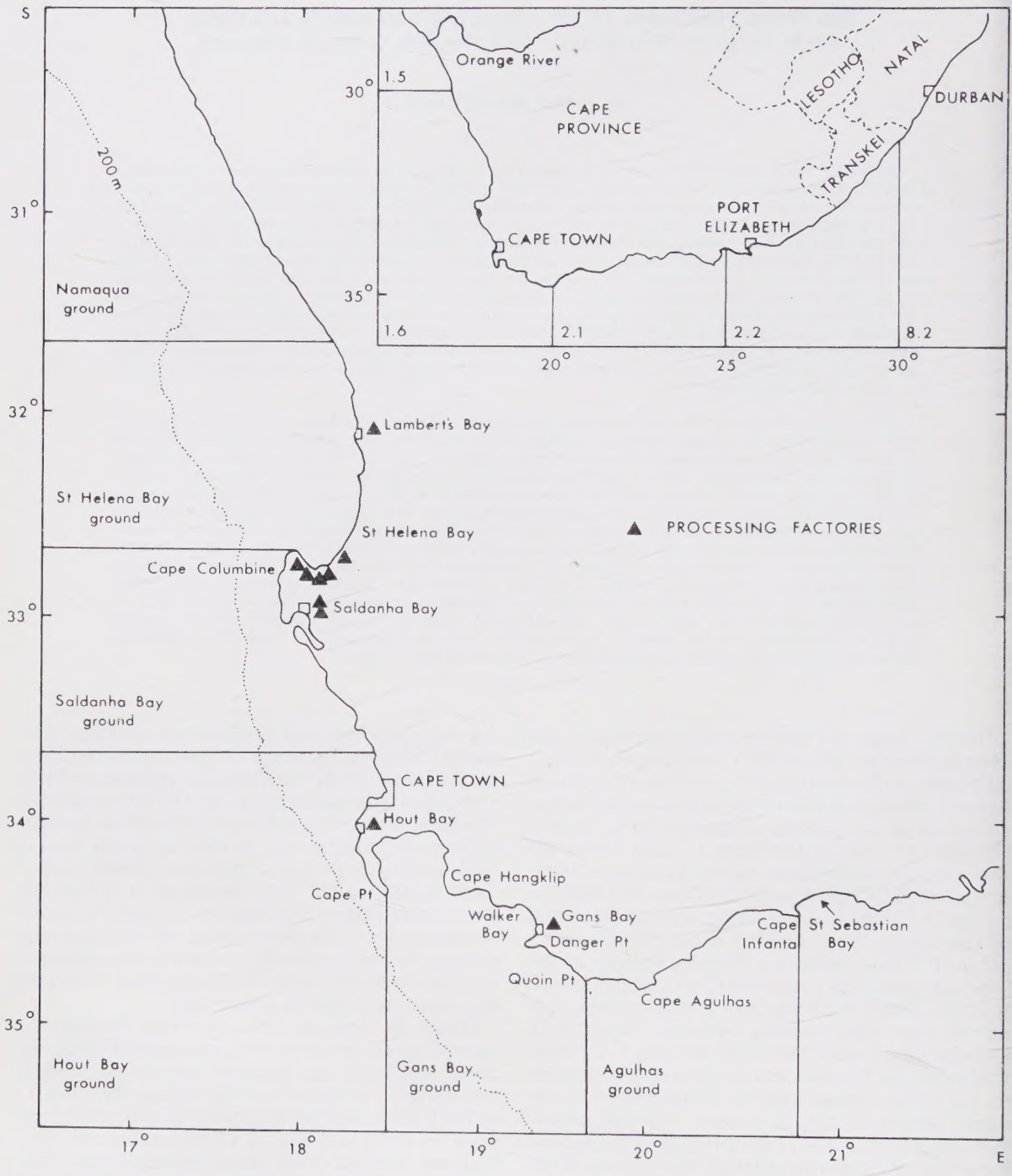

Fig. 1: The main South African purse-seine fishing grounds, showing the locations of the processing factories operative in 1976 and the ICSEAF divisions (inset)

Table I: Approximate South African demersal landings of horse mackerel per ICSEAF Division, 1950-1976 (after De Villiers 1977)

Year	Landings (metric tons) per Division				
	1.5	1.6	2.1	2.2	Total
1950	0	316	5	124	445
1951	0	905	8	192	1 105
1952	0	1 109	2	115	1 226
1953	0	1 407	3	46	1 456
1954	0	2 478	0	72	2 550
1955	4	1 733	1	192	1 930
1956	22	1 006	1	327	1 356
1957	26	769	7	183	985
1958	0	1 836	18	219	2 073
1959	0	1 636	101	338	2 075
1960	0	3 283	169	260	3 712
1961	0	3 174	187	266	3 627
1962	0	2 525	204	350	3 079
1963	0	880	273	248	1 401
1964	19	1 151	405	396	1 971
1965	54	1 188	537	582	2 361
1966	88	1 472	374	1 150	3 084
1967	3	1 296	450	1 633	3 382
1968	58	309	1 035	1 962	3 364
1969	81	1 382	2 571	1 859	5 893
1970	3	3 600	2 253	1 309	7 165
1971	17	2 057	4 379	1 299	7 752
1972	0	1 259	2 243	1 450	4 952
1973	13	1 814	3 045	2 158	7 030
1974	85	1 721	5 847	2 850	10 503
1975	139	1 657	4 544	2 271	8 611
1976	151	2 424	7 116	1 970	11 661

Table II: Landings of horse mackerel and their contribution to the total South African purse-seine catch, 1950-1976

Year	Landings (metric tons)	Proportion of total combined landings (%)
1950	49 913	36,9
1951	98 545	49,2
1952	102 607	37,6
1953	85 216	39,1
1954	118 142	56,1
1955	78 821	35,7
1956	45 752	29,5
1957	84 615	42,0
1958	56 428	20,6
1959	17 655	5,6
1960	62 926	15,3
1961	38 936	7,9
1962	66 650	13,4
1963	23 168	5,4
1964	24 351	5,7
1965	54 965	11,4
1966	26 329	7,4
1967	8 786	1,7
1968	1 433	0,4
1969	26 832	7,6
1970	7 942	2,2
1971	2 226	0,7
1972	1 335	0,3
1973	1 614	0,4
1974	2 451	0,6
1975	1 638	0,4
1976	417	0,1

40 per cent.

The fishery continued to develop in the early 1950's with the same two species maintaining their domination of the catches. The horse-mackerel harvest itself attained a peak of 118 000 tons in 1954, the only occasion on which it became the most important contributor to the mixed-species landings (Table II). This has been attributed to the excellent price which canned horse mackerel fetched on the United States market in that year (Du Plessis 1959). During other seasons there was no preferential fishing for horse mackerel.

From 1950 to 1958, catches of horse mackerel were based primarily on two large year-classes, those of 1947 and 1948 (Geldenhuys 1973), and landings averaged about 80 000 tons (Table II). On the passing of these two cohorts from the fishery, yields dropped to a lower level in the region of 40 000 tons which persisted, with fluctuations, until 1966 (Centurier-Harris *et al.* 1977). In this year, fishing for all species with a small-meshed (12,7-mm) net was first sanctioned and the result for horse mackerel was disastrous. Fishing pressure on the younger age groups increased and, between 1967 and 1976, the landings only once exceeded 10 000 tons.

DISTRIBUTION OF COMMERCIAL PURSE-SEINE CATCHES

Distribution patterns for commercial purse-seine catches made between 1964 and 1976 were derived in a manner similar to that described for the pilchard resource (Crawford 1981a). These patterns are presented in chart form in the Appendix, catch rates being given to depict spatial differences in the density of fish, and areas in which no fishing was conducted also being shown in order to assist in interpretation of the results. It should be borne in mind that, in 1964 and 1965, the season was closed for horse mackerel from August to October inclusive. Therefore, although good by-catches

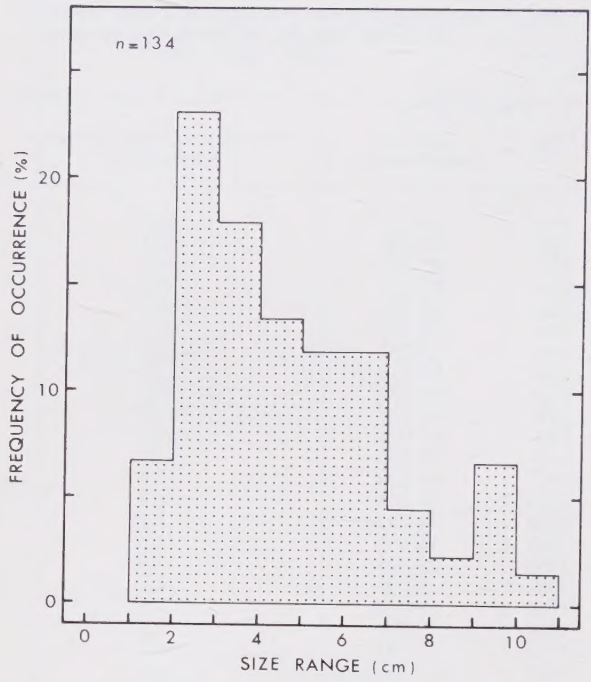

Fig. 2: Frequency of occurrence of size ranges (caudal length) of horse mackerel sampled from individual commercial purse-seine catches

were sometimes made while fishing for anchovy *Engraulis capensis*, catch per unit effort cannot be expected to provide an adequate measure of abundance in these months.

The modal length of fish caught in known localities is also shown, whenever this was available from field observations, to give some idea of geographical and seasonal differences in the size of horse mackerel encountered. Examination of the length distribution of horse mackerel in 134 purse-seine catches revealed that individuals from any one shoal can vary in caudal length by up to 11,0 cm (Fig. 2), but generally by not more than 7,0 cm. It is possible, therefore, that modal length may give a somewhat biased picture in a few instances, but the incidence of such bias is expected to be low.

Age at maturity has not yet been determined for horse mackerel in South African waters. For related species in the North Atlantic, it has been found that the majority do not spawn until they are three or four years old (Macer 1974). Similar results have been obtained for *T. trachurus* off South West Africa (Ja Lipskaja 1972). In the Appendix, however, only nought-year-old fish are depicted as juveniles. The procedure adopted therefore conforms to that employed for pilchard and anchovy (Crawford 1981a,c), the distribution of recruit year-classes being highlighted.

As with pilchard and anchovy, purse-seine catches of horse mackerel are seldom made to the seaward side of the 200-m (100-fm) bottom contour, except where this line approaches the mainland in the vicinities of Cape Columbine and Cape Point. The only known instances between 1964 and 1976 were of predominantly nought-year-old fish west of Dassen Island in August 1971, of four-year-olds north-west of the Olifants River in January 1965 and of seven-year-olds west of Cape Town in May 1969.

Apart from a few catches made off the Orange River (two-year-olds in May 1966, four-year-olds in July 1966, five-year-olds in June 1966), there are no records of catches from north of latitude 30° S, and fishing has also been poor at the south-eastern extremity of the grounds. The only successful hauls from east of Quoin Point were of one-year-old fish in January 1971 and April 1974 and of two-year-olds in April 1971.

The geographical distribution of commercial purse-seine catches therefore provides strong supporting evidence for the hypothesis that horse mackerel inhabiting the waters between the Orange River and Cape Agulhas form a discrete population, which may be distinguished from others located off Port Elizabeth and off South West Africa.

AVAILABILITY AND ABUNDANCE

Preliminary analysis of distribution data indicated that the horse-mackerel population of ICSEAF Divisions 1.5 and 1.6 could be subdivided into three distinct age components, nought-year-olds, fish aged one or two, and all older individuals. Accordingly, monthly indices of availability and of the relative abundance of fish that could, on average, be expected to be present on each of the six fishing grounds (Fig. 1) were determined for these three categories. The method employed was the same as that previously adopted for the pilchard (Crawford 1981a), though lack of adequate sample information precluded the use of data from 1968, 1975 and 1976. In addition, the data from 1964 and 1965 were not considered for nought-, one- or two-year-old fish because these younger fish would not have been fully selected prior to the intro-

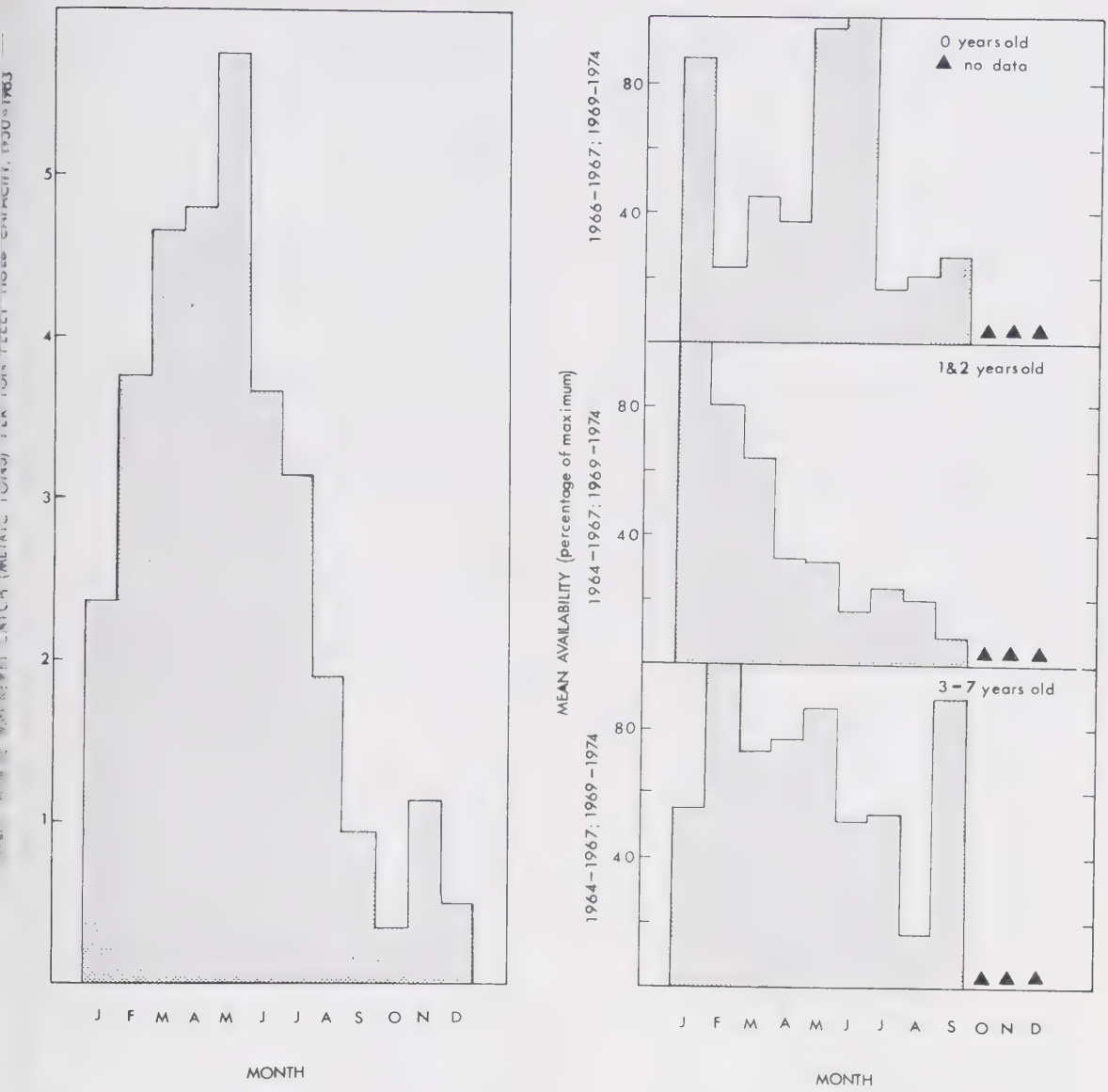

Fig. 3: Age-specific monthly availability indices for horse mackerel off South Africa

uction of the small-meshed net. The resulting stimates, expressed as percentages of the maxima, ppear in Figures 3 and 4.

ought-year-old fish

Availability indices for nought-year-old horse ackerel are difficult to interpret, with peaks in January and May/June separated by relatively low catch rates (Fig. 3). The trend is somewhat similar to those exhibited by three typical spring/summer spawners, pilchard, anchovy and round herring, with the exception that availability of these species remains at a high level during late winter and early spring (Crawford 1981a,c,d). Furthermore, although Geldenhuys (1973), on the basis of a finding of increased availability of large fish in

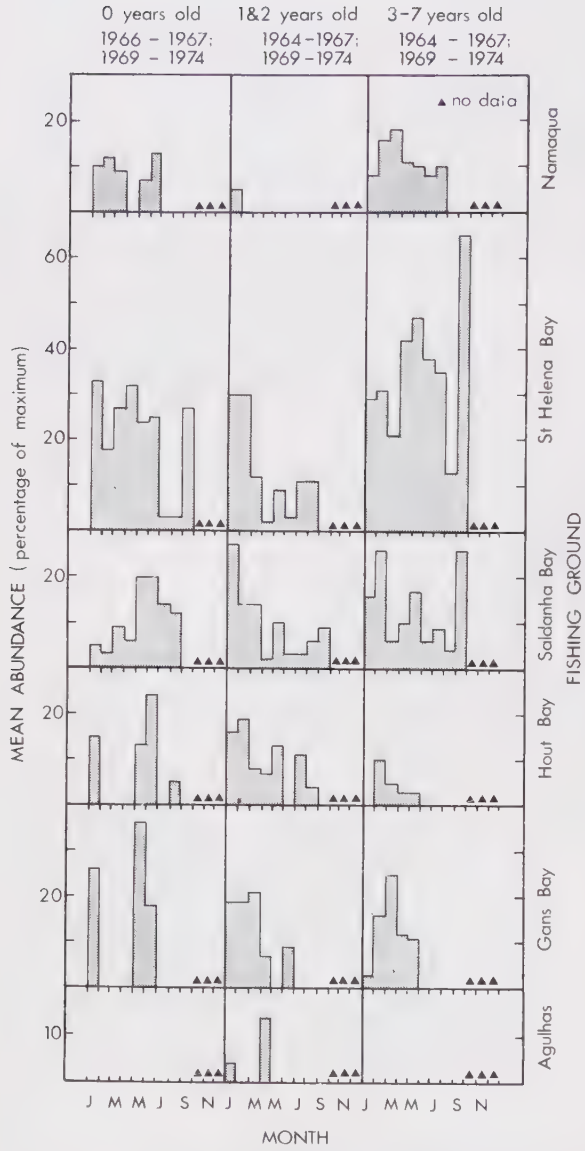

Fig. 4: Age specific monthly abundance indices for horse mackerel for six fishing grounds

winter, postulated that spawning may take place during that season, the initial results of a recent plankton survey (P.A. Shelton, Sea Fisheries Institute, personal communication) suggest that most egg production takes place in spring and early summer between Saldanha Bay and Cape Hangklip in deep off-shore water. Off South West Africa the main spawning season is summer and early autumn (O'Toole 1977). The low availability indices calculated for July, August and September may, therefore, be an incorrect representation of the general pattern. Between 1966 and 1976, yields of horse mackerel were frequently low (Table II) and this may have resulted in an inaccurate allocation of effort (Crawford 1981b). In particular, nought-year-olds were not encountered in 1964, probably because of unsuitable gear, or in 1972, and relatively insignificant catches for which no age information is available were made in 1975 and 1976. Even in other years, catch rates never exceeded 10 metric tons per standard-boat-day (Appendix).

From Figure 4 it is evident that, throughout the period under review, nought-year-old fish were most abundant in the St Helena Bay region, entirely absent from the Agulhas area, and contributed only moderate yields on all the other fishing grounds.

One-and two-year-old fish

The availability of one- and two-year-old horse mackerel is at its highest in January and decreases steadily thereafter (Fig. 3). A total mortality coefficient (Z) of 3,6 would be required to produce the observed trend, but this seems unrealistic in view of the fact that natural mortality of horse mackerel in the South-East Atlantic is not expected to exceed 0,25 (Draganik 1977). Estimates of the fishing mortality inflicted on the species by the South African purse-seine fishery ranged from 0,01 to 0,13 (mean 0,07) between 1950 and 1962 (Centurier-Harris *et al.* 1977), but unfortunately no equivalent estimates are available for the period under consideration. Although exploitation of the younger age groups increased with the introduction of a small-meshed net, a much higher coefficient would be required to make up the discrepancy.

One- and two-year-old horse mackerel are found primarily on the four central fishing grounds (Fig. 4) but, although they appear to assume a slightly more southerly distribution than either younger or older individuals, no regular migrations off the fishing grounds can be discerned. In 1971, two-year-old fish were caught between Dassen Island and Cape Point in February, from Hout Bay to Quoin Point in March, and in Walker Bay and east of Cape Agulhas in April (Appendix). In 1974, one-year-olds were encountered off Cape Town and from Cape Point to Quoin Point in March and were located off Cape Town and to the west of Cape Infanta in April. It is possible

herefore, that in these two years the relevant year-classes moved in a south-easterly direction, as do pilchard aged between two and four years during similar months (Crawford 1981a) and as, sometimes, do shoals of adult anchovy (Crawford 1981c). This is not always the case, however, and cannot itself account for the decline in availability.

Other possible reasons for the fall in catch rates are not easy to determine. In the North Atlantic, horse mackerel as they grow older gradually change their diet from zooplankton to include a greater proportion of fish. Also, they are often present in substantial numbers in dense overwintering shoals, which form along the edge of the continental shelf from the southern Bay of Biscay to about latitude 49°N at depths of 180-250 m (Lockwood and Johnson 1977). Should a similar pattern of behaviour occur in South African waters, it would certainly result in a reduced availability of these young fish to purse-seiners. Feeding studies conducted off South West Africa and Angola indicate that copepods and euphausiids dominate in the diet of most age classes (Venter 1976), although myctophids are also ingested by fish aged four and older (Ja Lipskaja 1972, Kompowski and Slósarczyk 1976). However, information on changes in feeding habit with age is at present scarce.

Three- to seven-year-old fish

Indices for the older horse-mackerel age groups suggest that these fish are most available from late summer through midwinter (Fig. 3). The high catch rates recorded in September may not be an accurate reflection of the true situation. As mentioned earlier, there was a lack of adequate data for the period under consideration when horse-mackerel harvests were generally poor. Moreover, a change in the prescribed minimum mesh size from 32,0 to 12,7 mm meant that the fishing mortality inflicted on young fish was increased with a resultant lessening of the contribution of fish aged three and older to the landings (Fig. 5). Between 1950 and 1963, total horse-mackerel yields were considerably higher (Table I), fish younger than three years were not fully selected by the fishing gear (Crawford *et al.* 1978), and mean monthly levels of catch per unit effort, though confirming the increased availability experienced between February and July, indicate that only low returns were made in September (Fig. 3). In arriving at these estimates, the effort expended during any particular month was allocated to individual species *pro rata* to their contribution to the combined catch. The general pattern of availability was first noted by Geldenhuys (1973), who demonstrated that large horse mackerel dominated the winter catches in a very regular fashion.

Horse mackerel three to seven years old are most abundant in the St Helena Bay area, moderately so on the Namaqua and Saldanha Bay grounds, and less abundant further south (Fig. 4). Their distribution is thus similar to that of the nought-year-old fish.

Five- and six-year-old pilchard and adult mackerel also favour the northern fishing grounds, and both these components of the mixed-species pelagic stocks show similar trends in availability to that exhibited by older horse mackerel (Crawford 1980). In the case of pilchard, the low catch rates of spring and summer have been attributed to individuals of the species moving away from the coast to spawn (Davies 1956) whereas, for mackerel, Baird (1978) described a winter spawning migration of adults from off-shore to inshore waters. It is probable that horse mackerel in South African waters spawn between spring and early autumn, and their behaviour would therefore seem more to parallel that of the pilchard population. Although wind-driven upwelling is at a minimum in winter, storm-induced mixing maintains a narrow strip of cool, plankton-rich water close to the coast in the region north of Cape Columbine (Crawford *et al.* 1980). The inshore presence of adult pilchard and horse mackerel, when not spawning, might therefore be associated with feeding.

DISCUSSION

The domination of commercial and other fisheries by strong horse-mackerel year-classes has been described by a number of authors (Geldenhuys 1973, Macer 1977, Newman and Centurier-Harris 1977). Unfortunately no exceptional recruitment of the species took place in South African waters during the period under review, but it is nevertheless possible to trace the progression of certain cohorts on the distribution maps.

As mentioned earlier, nought-year-olds were not fully selected prior to 1966 but, in spite of this, they appeared in the catches during the latter part of 1965, being fairly frequently encountered in the region between Lambert's Bay and Cape Town

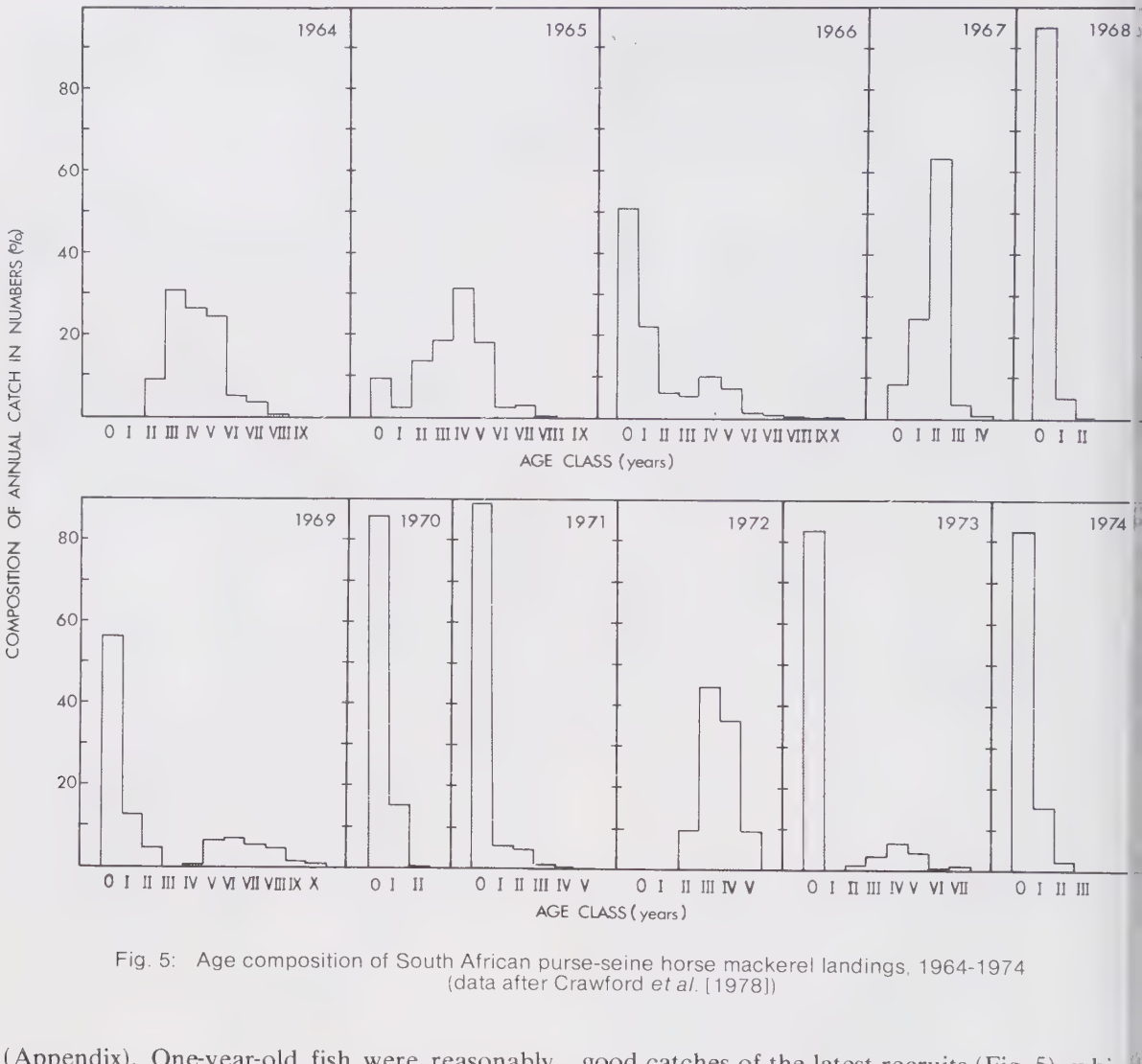

Fig. 5: Age composition of South African purse-seine horse mackerel landings, 1964-1974 (data after Crawford *et al.* [1978])

(Appendix). One-year-old fish were reasonably plentiful during the first four months of 1966, especially in January, when catches were made between north of the Olifants River and Cape Columbine, outside Hout Bay and in False Bay. As two-year-olds the same cohort dominated the landings of 1967 (Fig. 5). Again they were fished between Lambert's Bay and Cape Point (January, April, August), although good yields were also recorded in the Walker Bay vicinity (January —May), where catch rates exceeded 25 metric tons per standard-boat-day on occasion.

In 1969, almost 27 000 metric tons of horse mackerel were landed, the only occasion that 10 000 tons have been exceeded since the legalizing of the 12,7-mm net in 1966. The cause was largely the good catches of the latest recruits (Fig. 5), whic were present on the northern fishing grounds i January, March, April and June, as well as in th vicinity of Cape Point in January. During th following season, relatively high yields of one year-old fish were recorded between Cap Columbine and Cape Town in January. These fis were also encountered from north of the Olifant River to St Helena Bay, and they persisted in th catches during February and March. In Januar 1971, they reappeared as two-year-olds on th southern grounds, where they were fished unt early winter, and the same cohort dominated th landings of the two succeeding years (Fig. 5). I 1972, they were caught between January and Ma from the Olifants River in the north to Gans Ba

in the east, and in 1973 during late summer and autumn over much the same area.

The 1965 and 1969 year-classes therefore conformed in large measure to the overall patterns of distribution and availability. That of 1969 may well have developed into a significant factor in the fishery had it not been subjected to intensive exploitation during its early stages. Indeed, a feature of the horse-mackerel landings between 1966 and 1976 was the noticeably young age structure of the catches (Fig. 5), and there seems little doubt that this was primarily responsible for the greatly reduced yields (Table II). The situation is unlikely to improve until some means of avoiding the latest recruits is established but, on account of the almost identical behaviour exhibited by nought-year-old pilchard, anchovy and horse mackerel, this will prove to be no easy task.

ACKNOWLEDGEMENTS

The author wishes to thank Professor J.G. Field (University of Cape Town), Drs L. Hutchings and G.G. Newman and Messrs H.G.v.D. Boonstra, G. de Villiers and A.I.L. Payne for their many helpful comments on the various versions of the manuscript. Messrs S.R. da F. Baptista and S. Hagan and Mrs P. Crawford devoted considerable effort to the artwork. The Fisheries Development Corporation of South Africa Ltd assisted with the funding of the study.

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This report is based on a section of a dissertation submitted in September 1979 as part requirement for the degree of Doctor of Philosophy at the University of Cape Town.

APPENDIX

HORSE-MACKEREL CATCH LOCATIONS 1964-1976

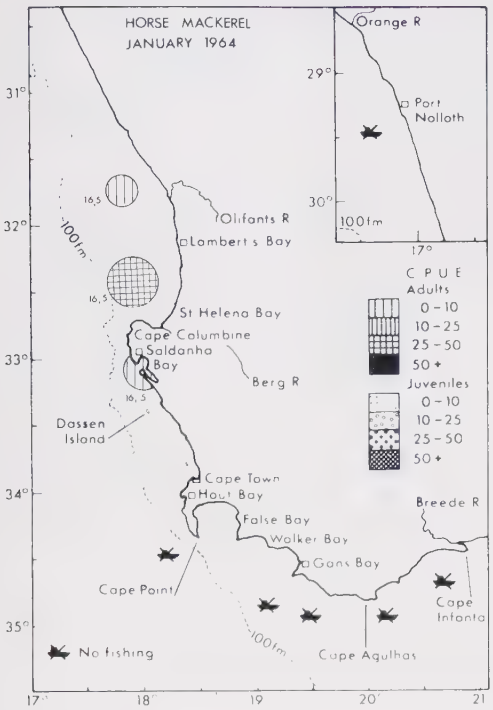
From 1969 to 1976 no maps are shown for September — December inclusive, because exploitation of horse mackerel was prohibited during these months.

Levels of catch per unit effort (C.P.U.E.) are indicated as metric tons per standard-boat-day.

Modal caudal lengths (cm) of fish from different areas are shown adjacent to catch locations. Growth rates may be expected to vary between seasons, but some indication of age is provided by the von Bertalanffy growth equation calculated by Geldenhuys (1973).

Age (years)	Predicted caudal length (cm)
1	7.0
2	11.7
3	15.8
4	19.4
5	22.6
6	25.4
7	27.9
L_∞	46.3

Areas in which there was no deployment of fishing effort are shown.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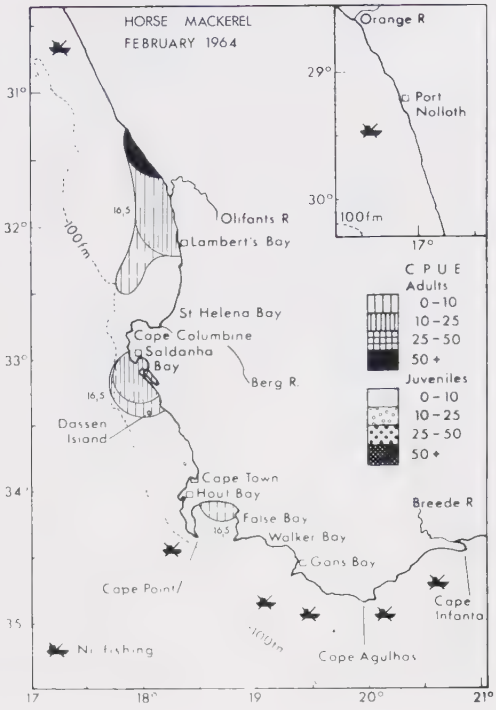
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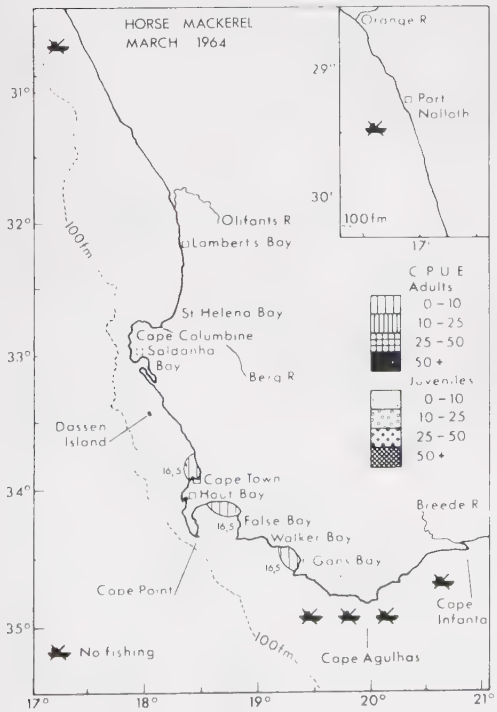
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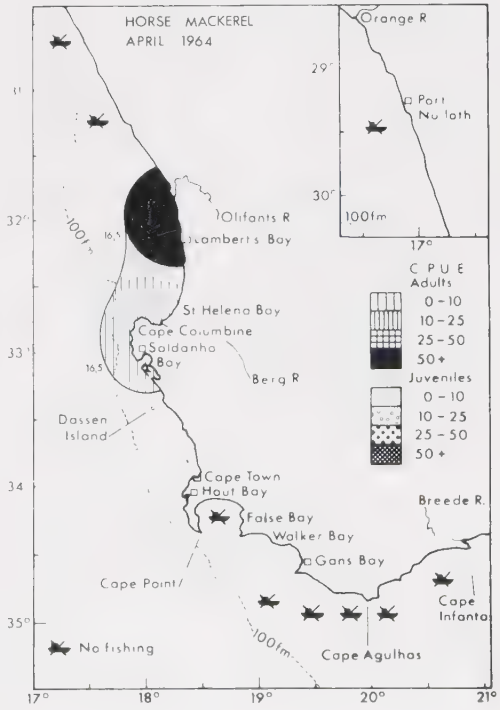
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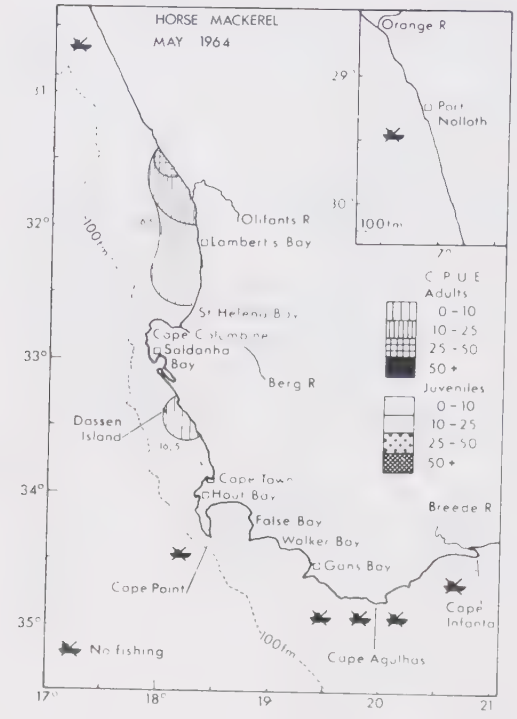
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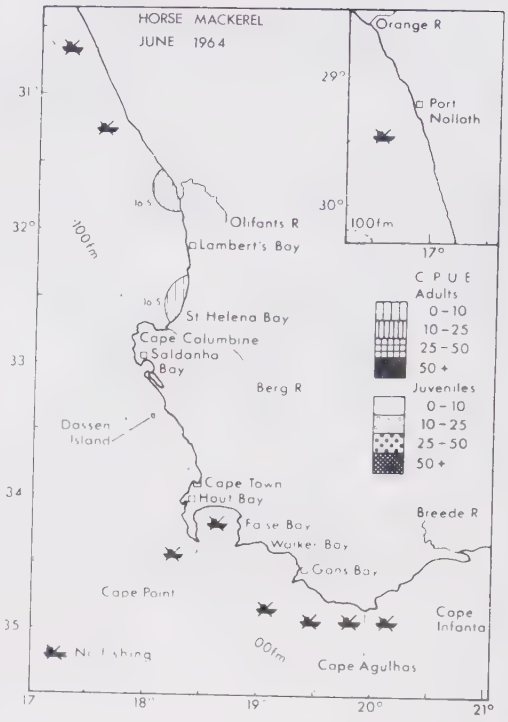
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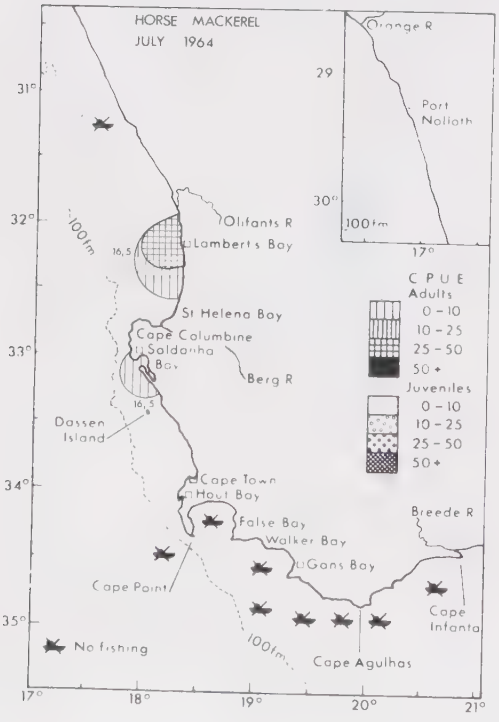
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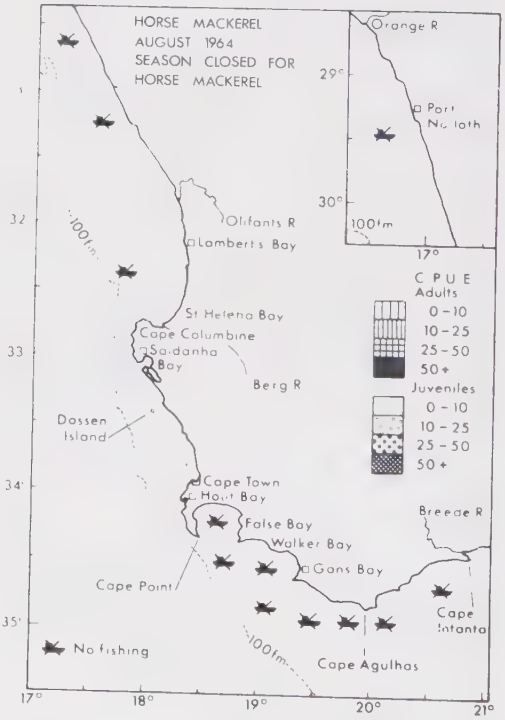
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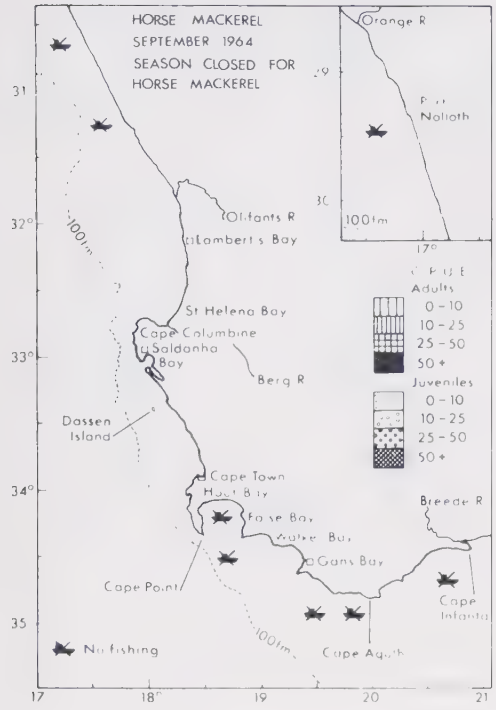
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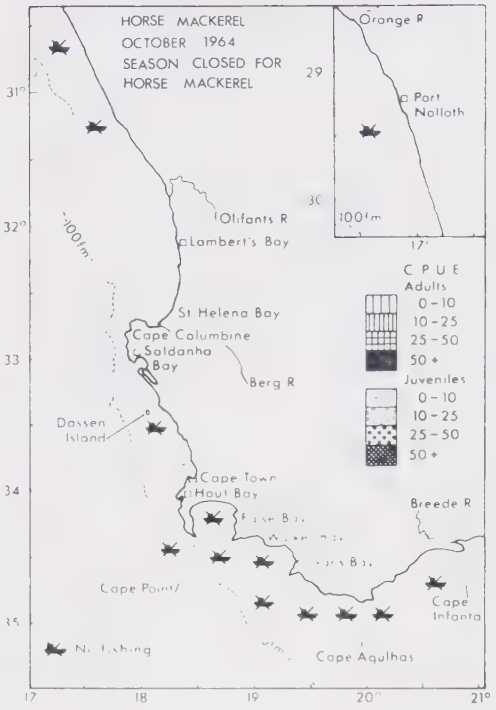
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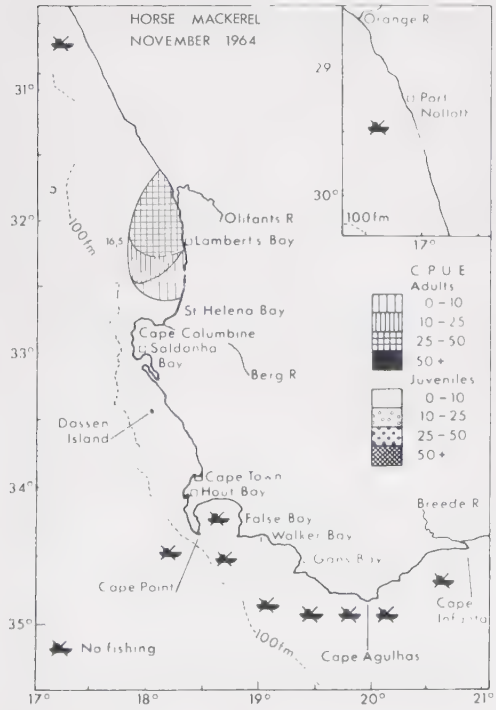
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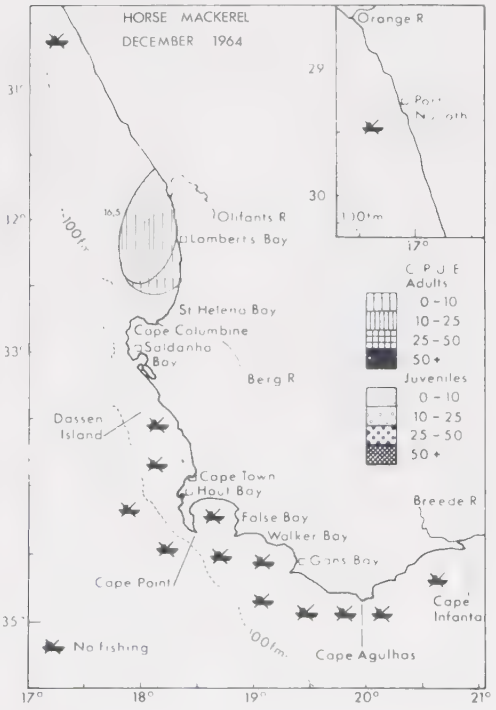
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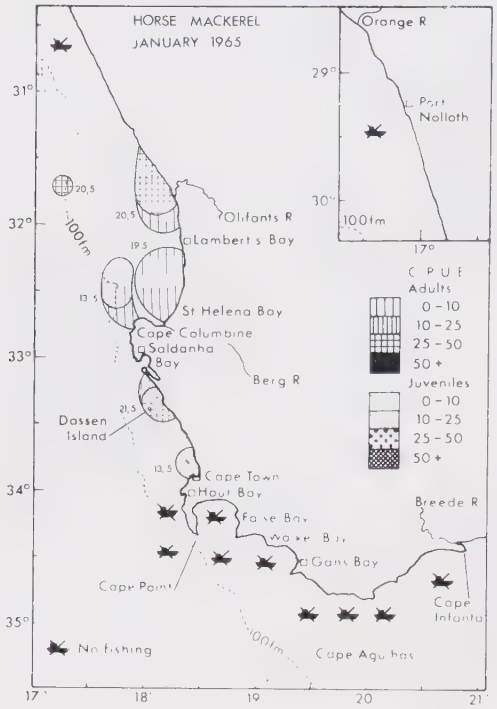
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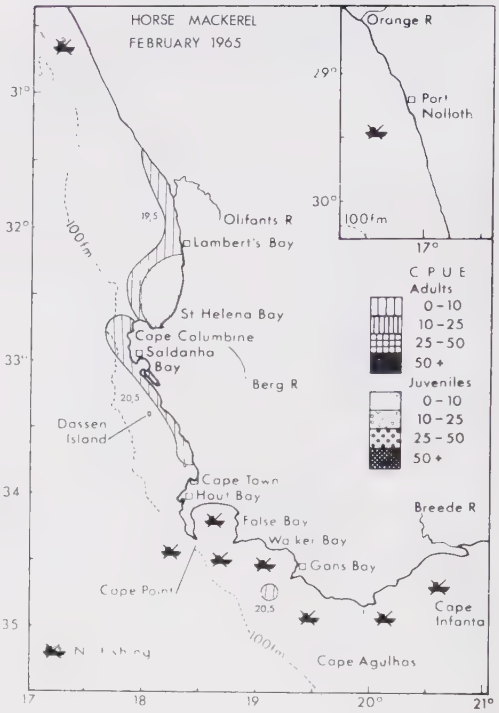
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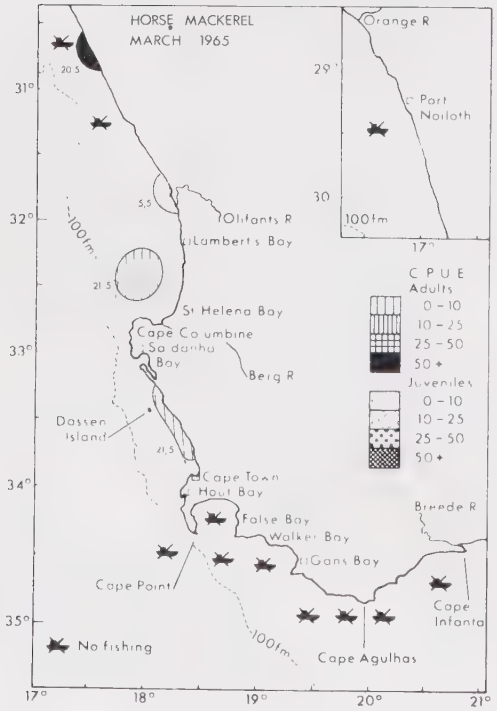
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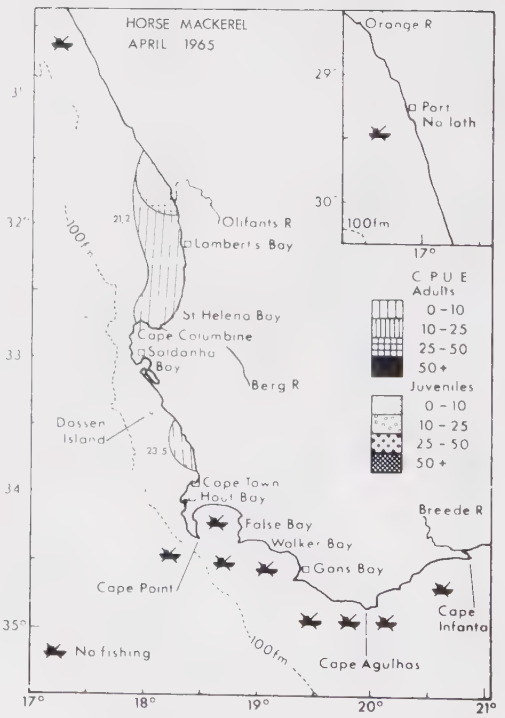
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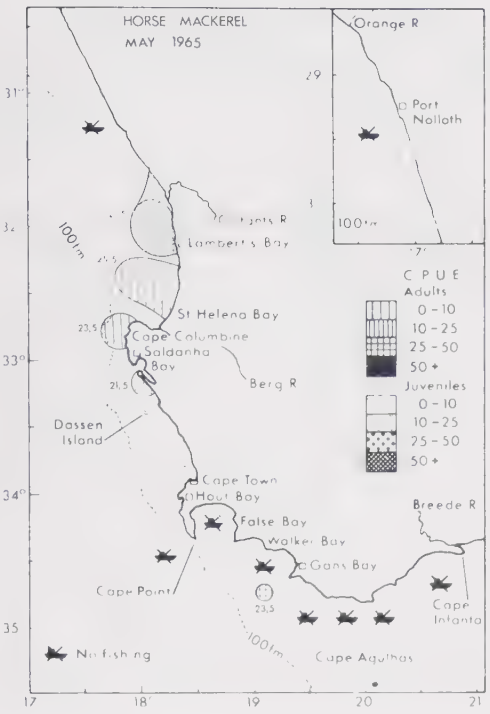
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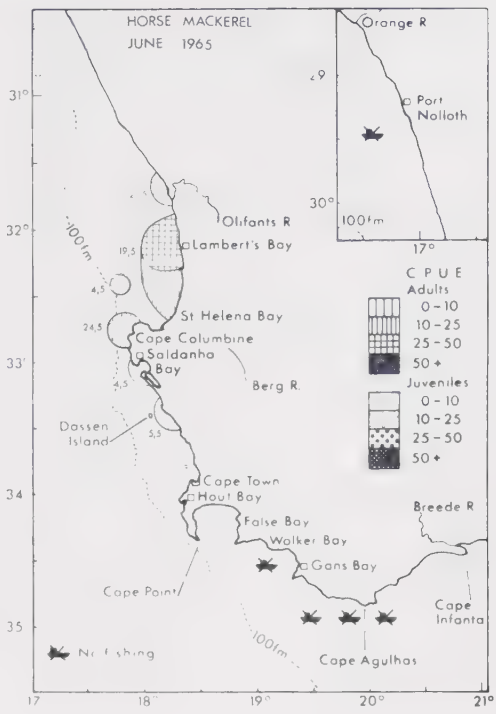
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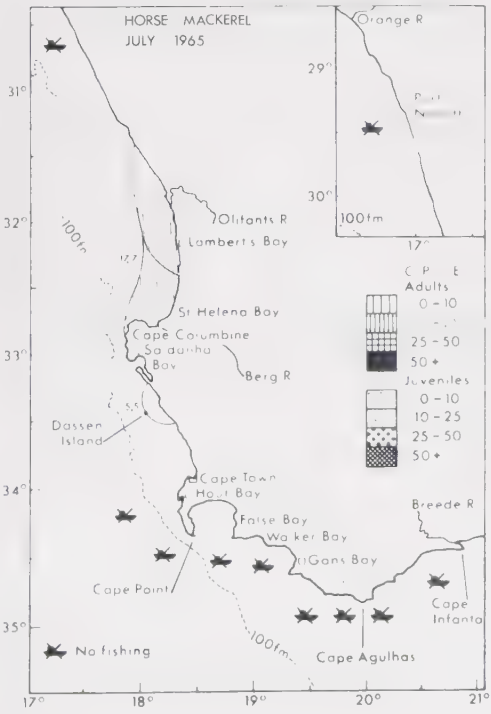
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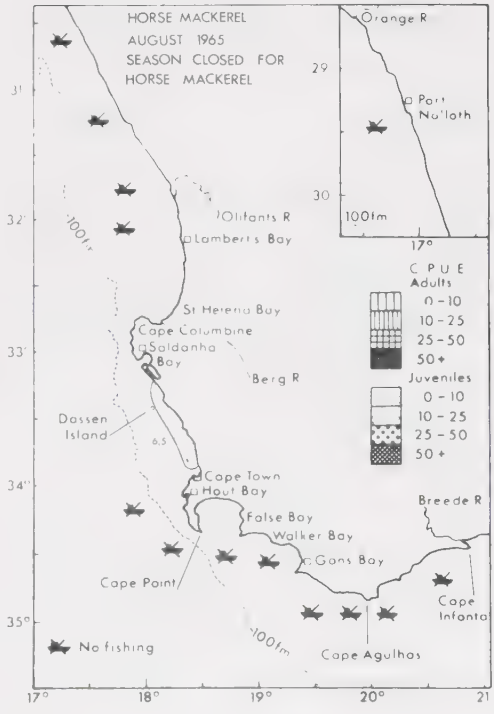
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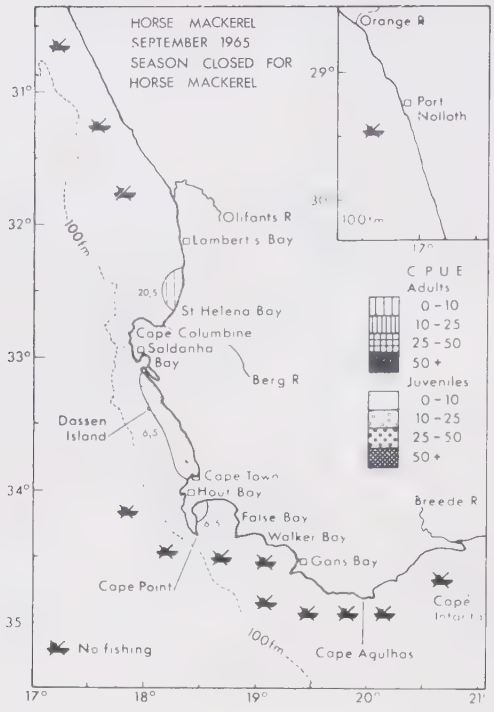
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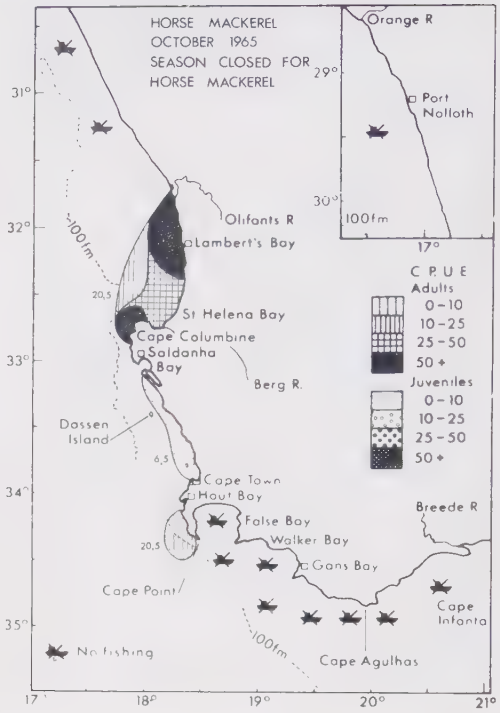
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OCTOBER 1965
SEASON CLOSED FOR
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Cape Point
Cape Infanta
Cape Agulhas
Breede R
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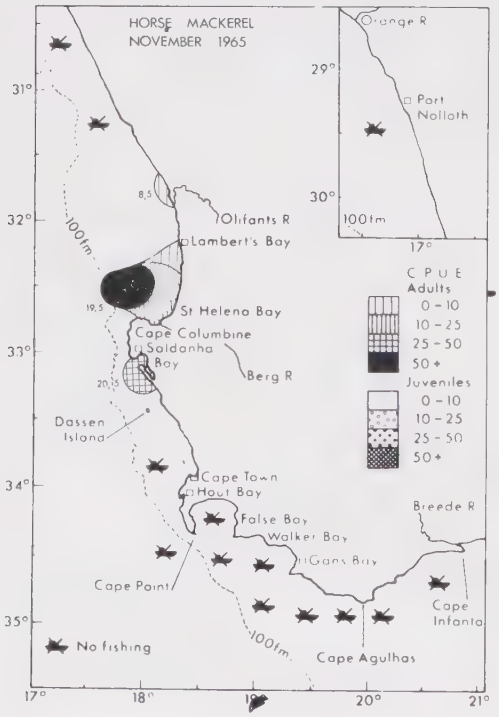
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Saldanha Bay
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Dassen Island
Cape Town
Hout Bay
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Breede R
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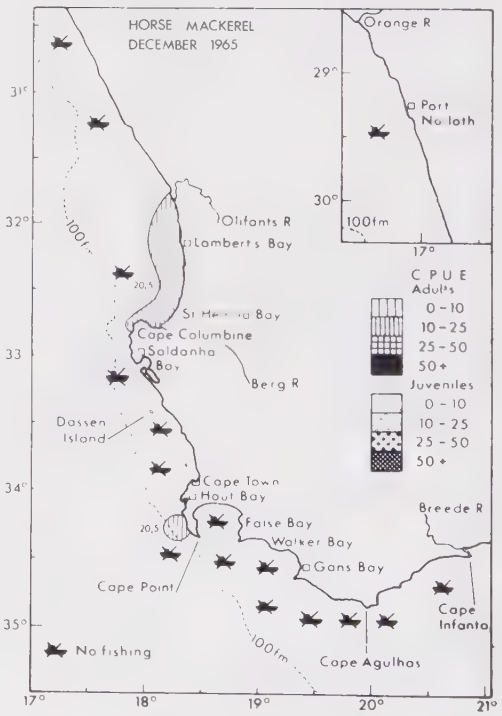
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Cape Town
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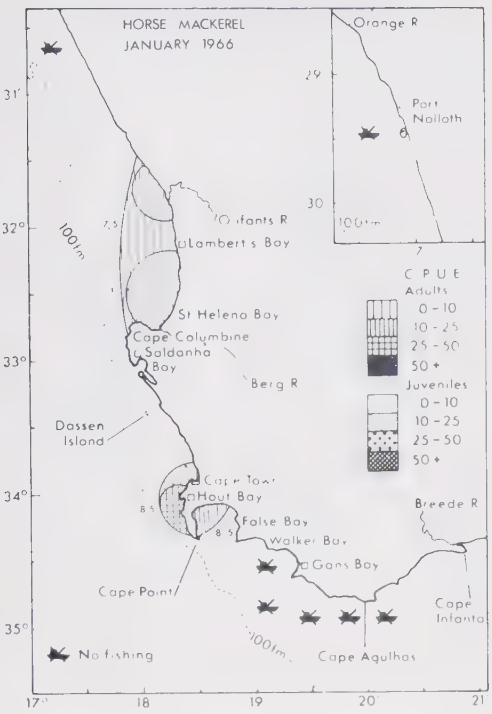
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JANUARY 1966
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Dassen Island
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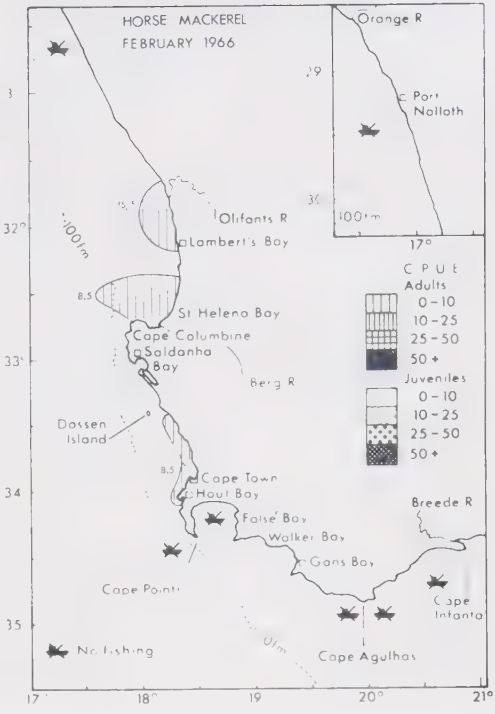
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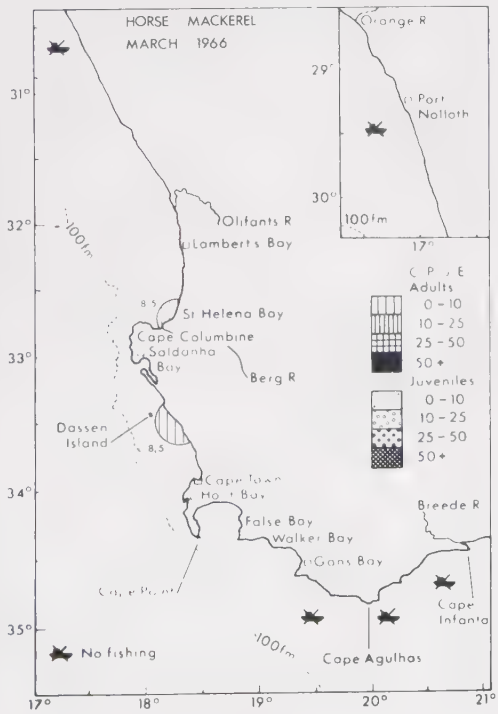
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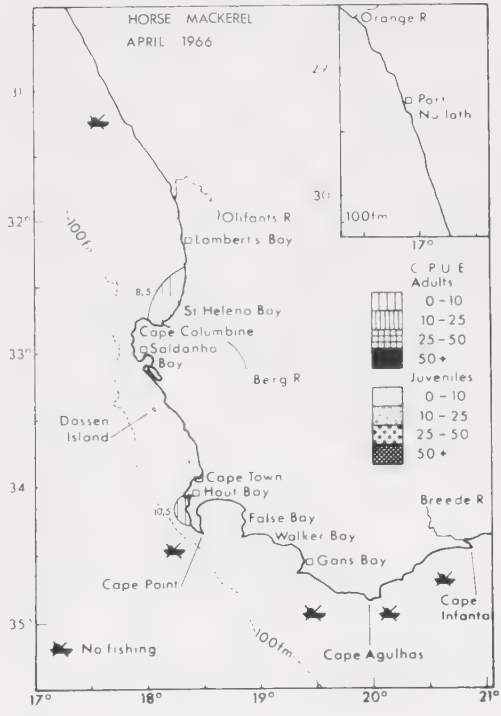
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APRIL 1966
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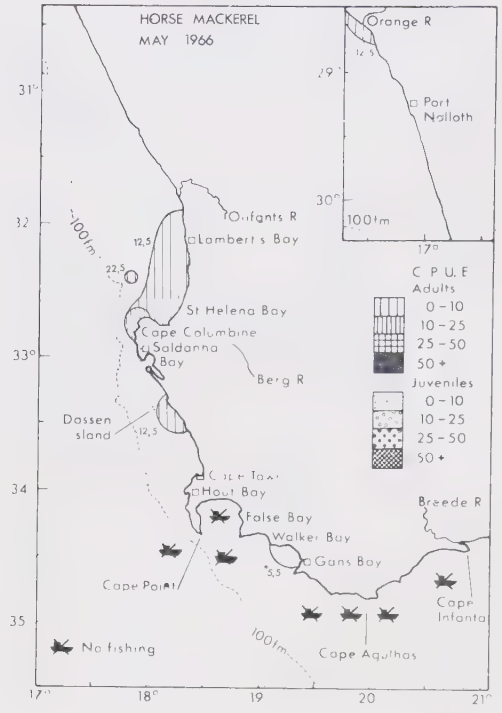
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MAY 1966
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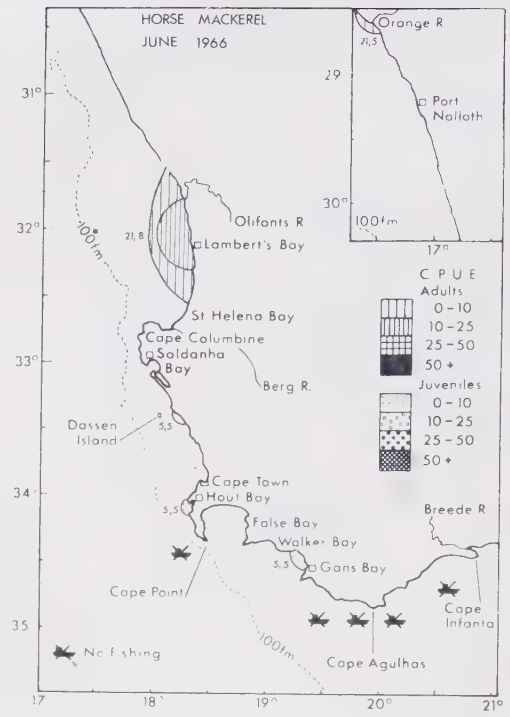
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JUNE 1966
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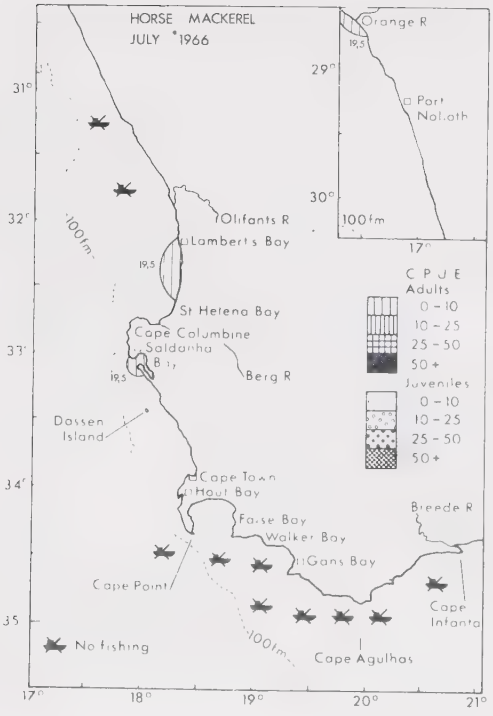
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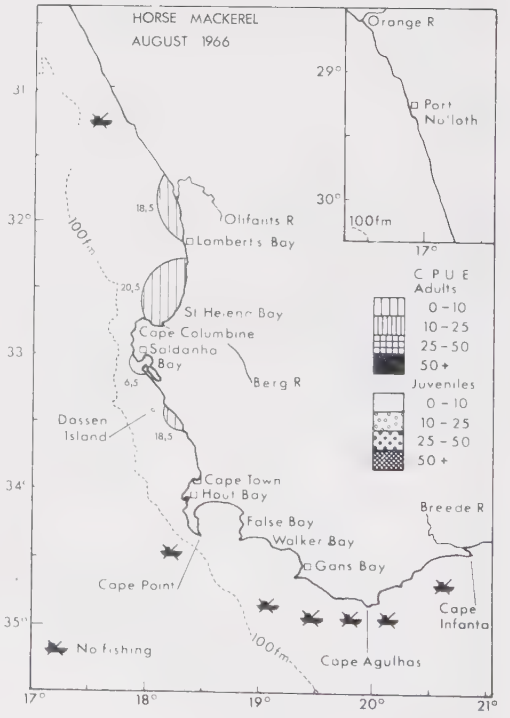
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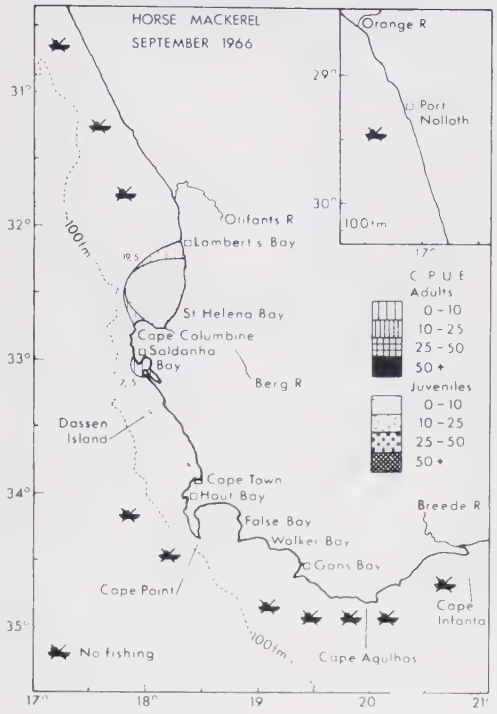
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
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Dassen Island
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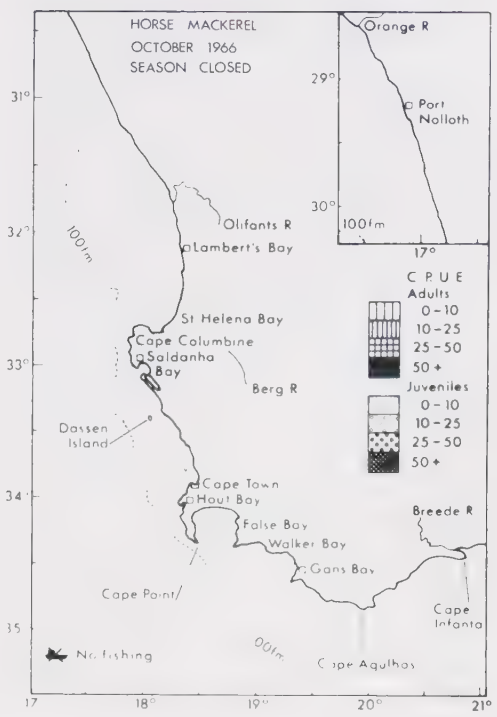
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
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False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
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100fm
Cape Agulhas
No fishing
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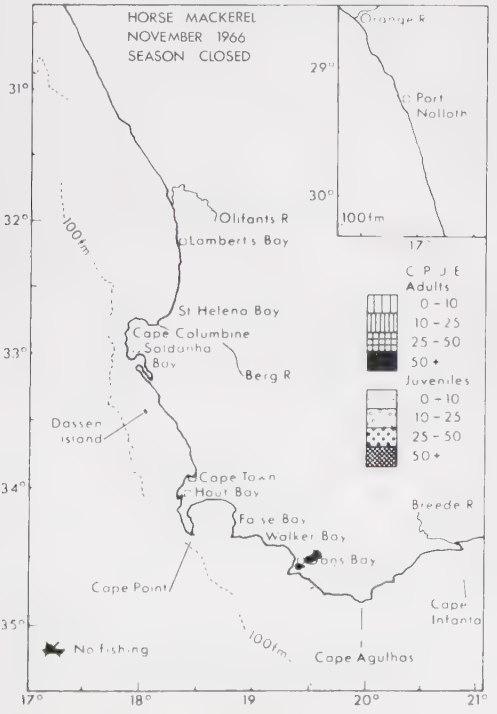
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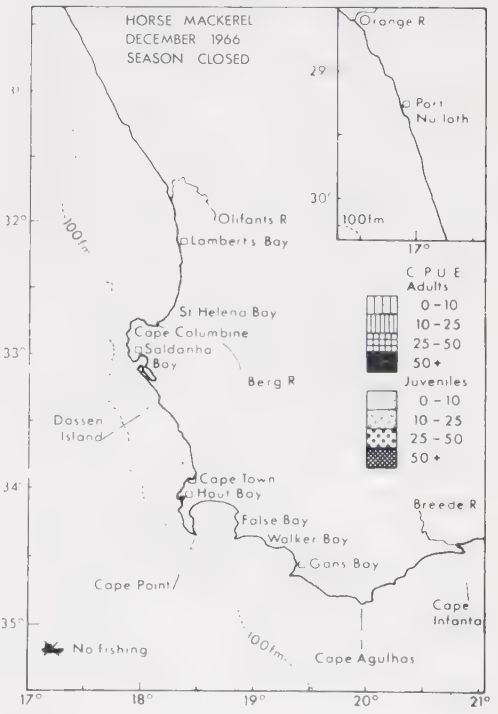
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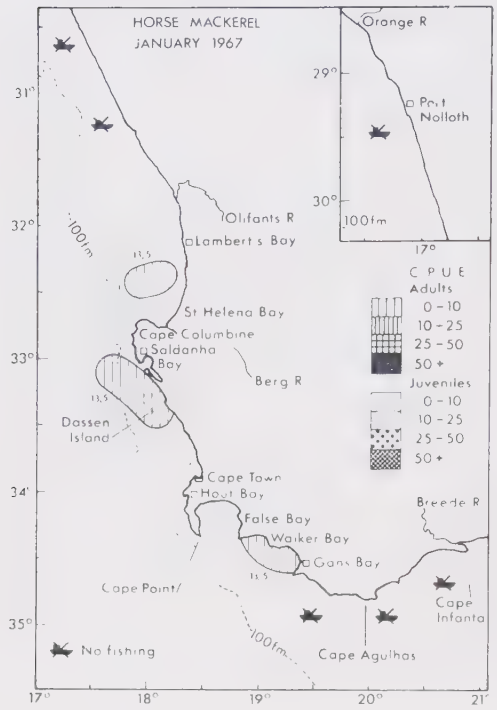
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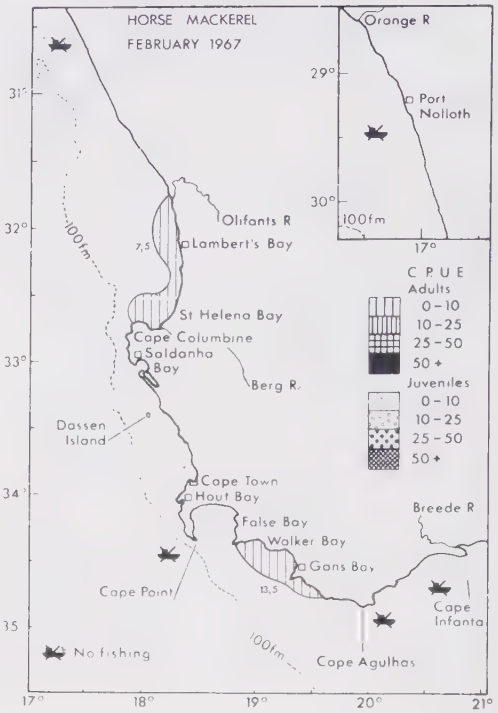
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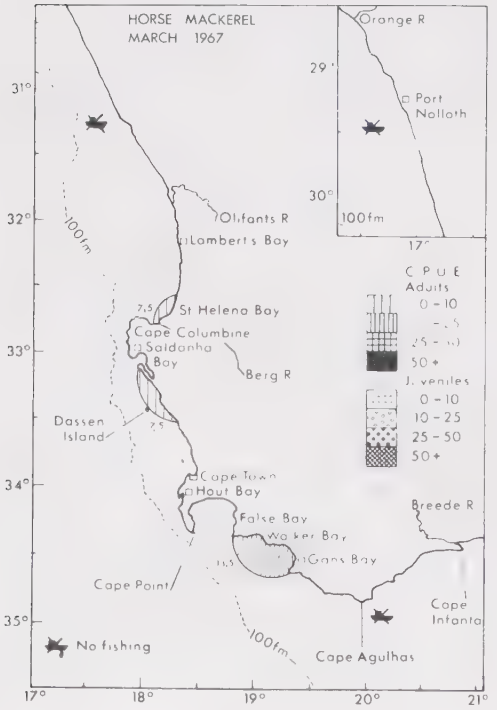
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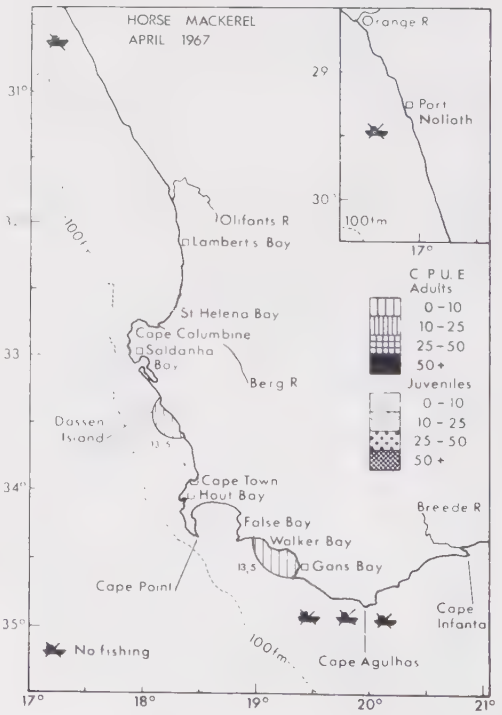
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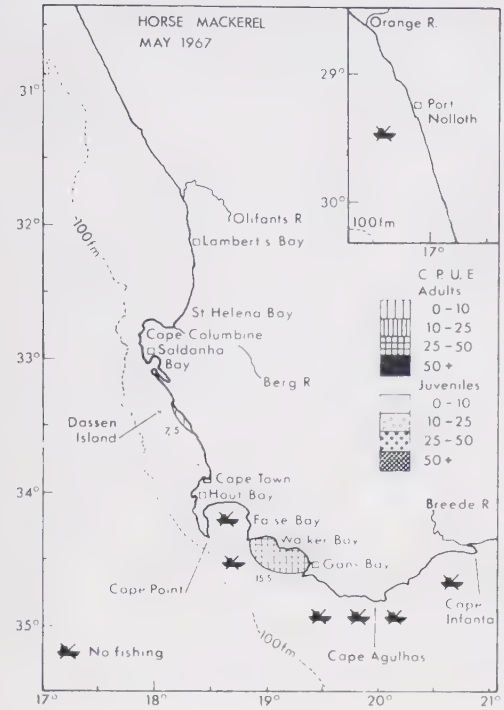
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MAY 1967
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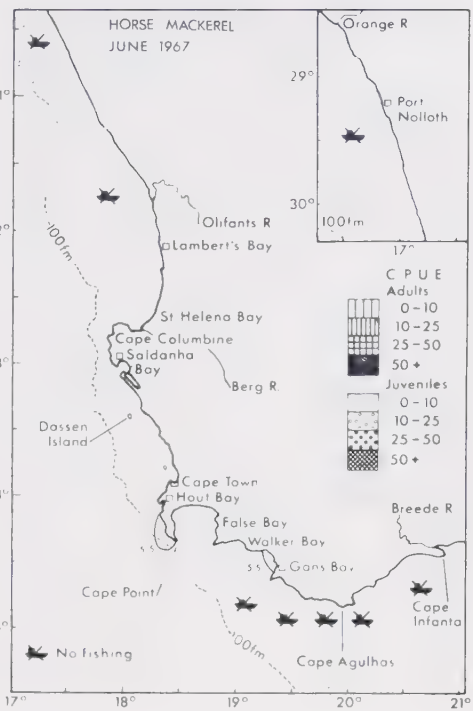
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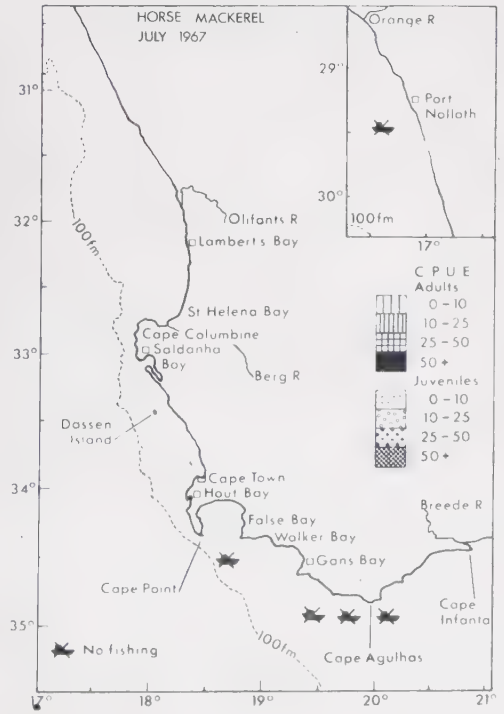
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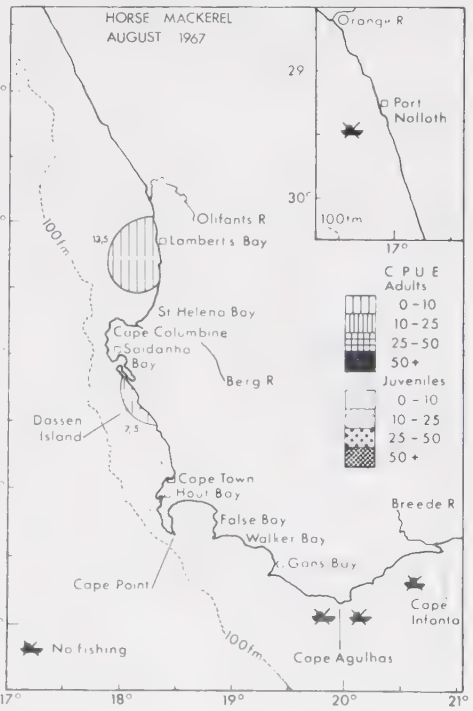
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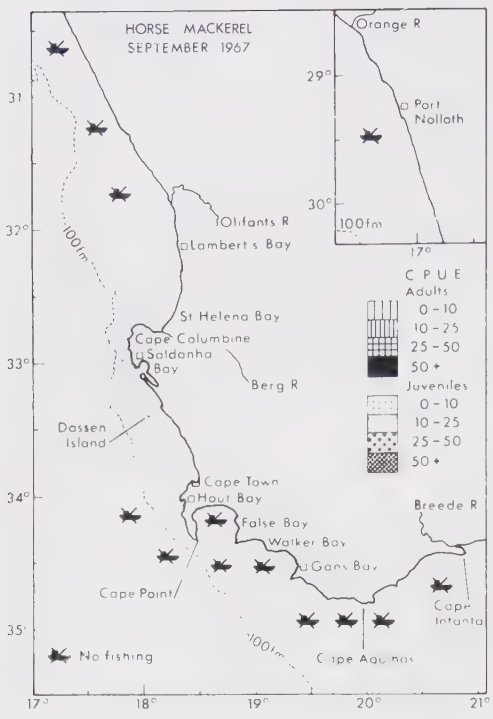
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SEPTEMBER 1967
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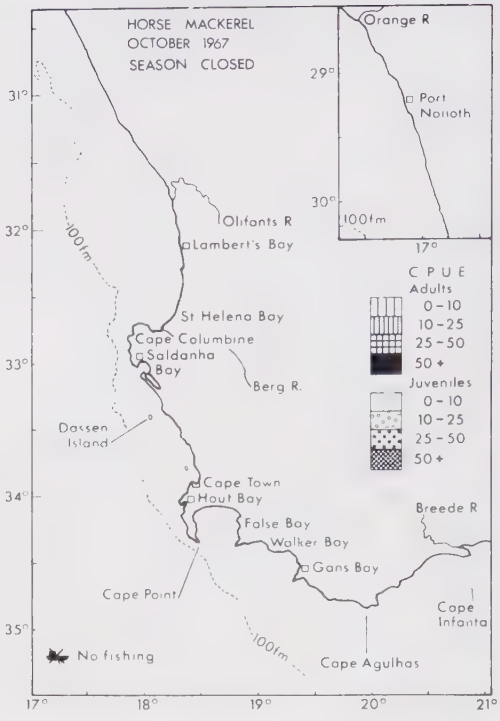
HORSE MACKEREL
OCTOBER 1967
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Cape Infanta
Cape Agulhas
100fm
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Juveniles
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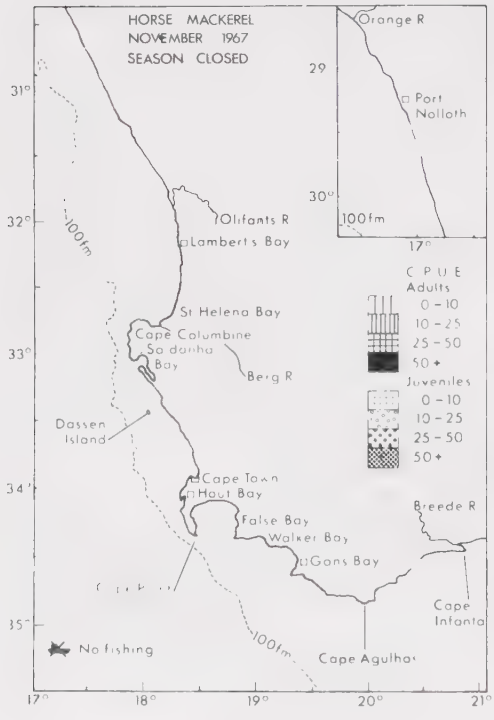
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NOVEMBER 1967
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Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Infanta
Cape Agulhas
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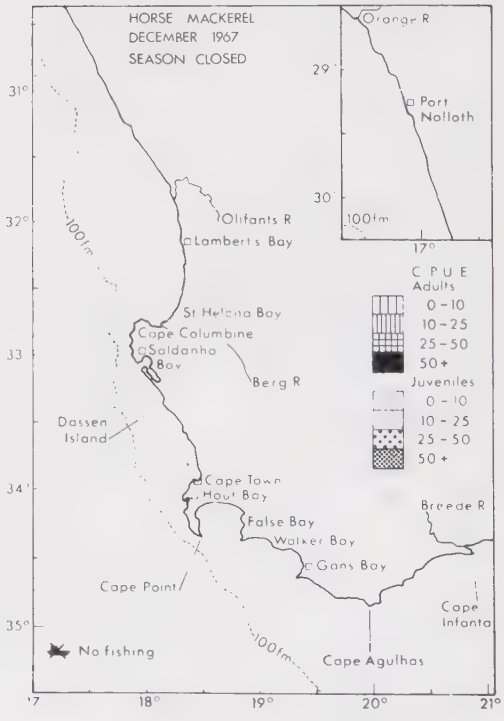
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Port Nolloth
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Lambert's Bay
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Cape Columbine
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Berg R
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Cape Infanta
Cape Agulhas
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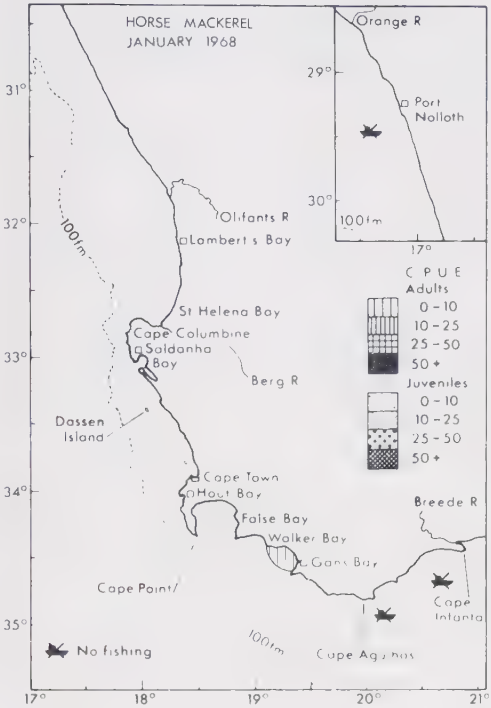
HORSE MACKEREL
JANUARY 1968
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
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Gans Bay
Breede R
Cape Point
Cape Infanta
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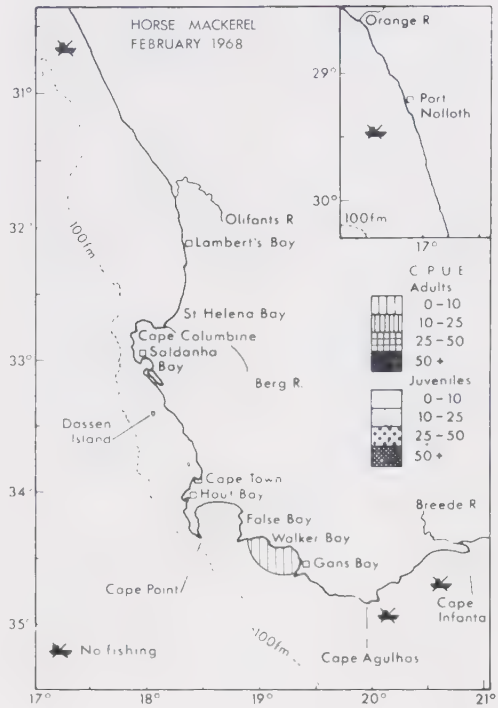
HORSE MACKEREL
FEBRUARY 1968
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Lambert's Bay
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Berg R
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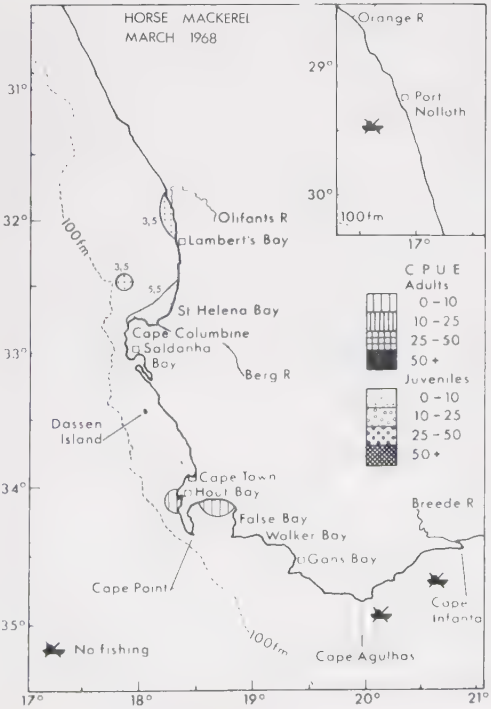
HORSE MACKEREL
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Dassen Island
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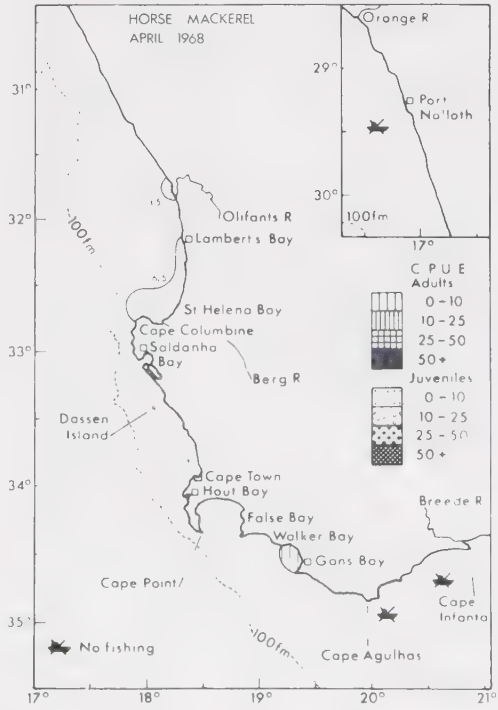
HORSE MACKEREL
APRIL 1968
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Lambert's Bay
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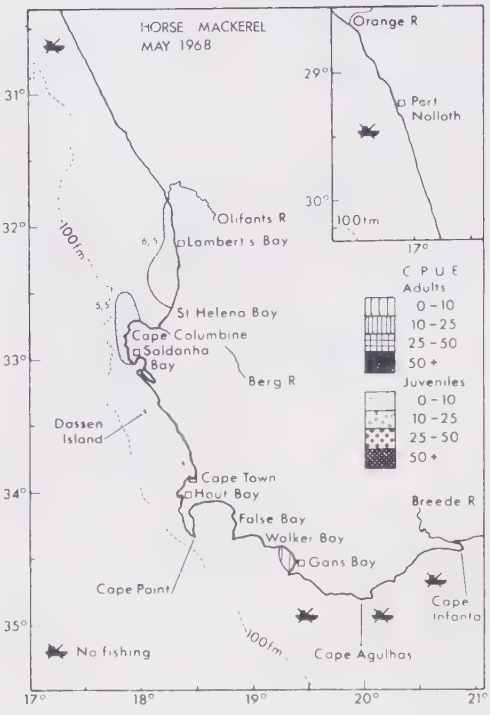
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MAY 1968
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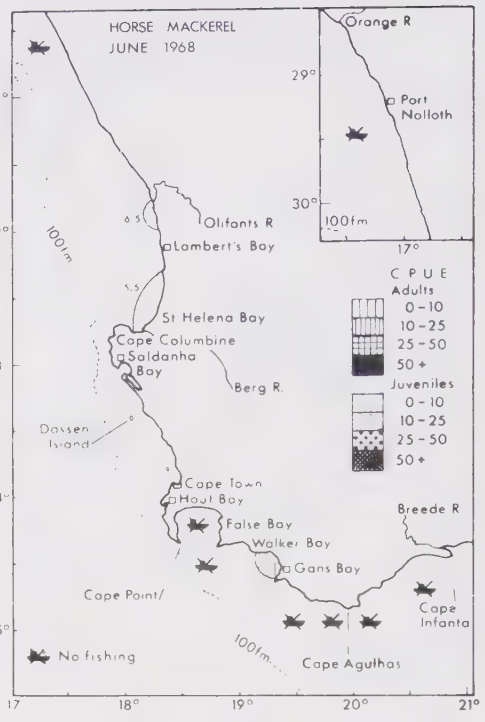
HORSE MACKEREL
JUNE 1968
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
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Gans Bay
Breede R
Cape Point/
Cape Infanta
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Juveniles
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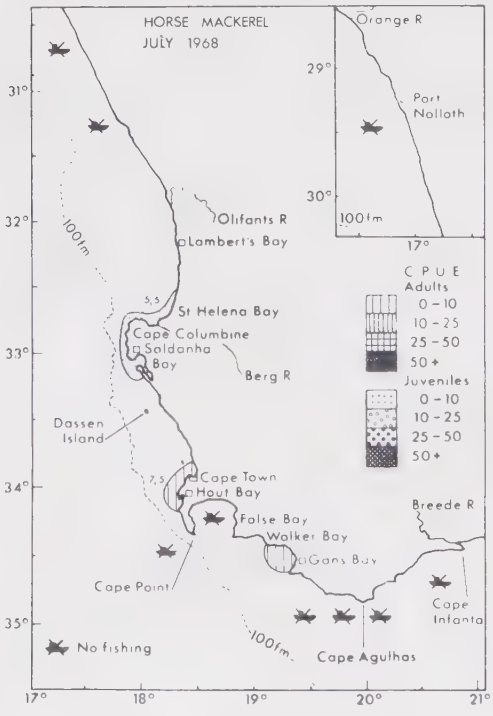
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JULY 1968
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Dassen Island
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Juveniles
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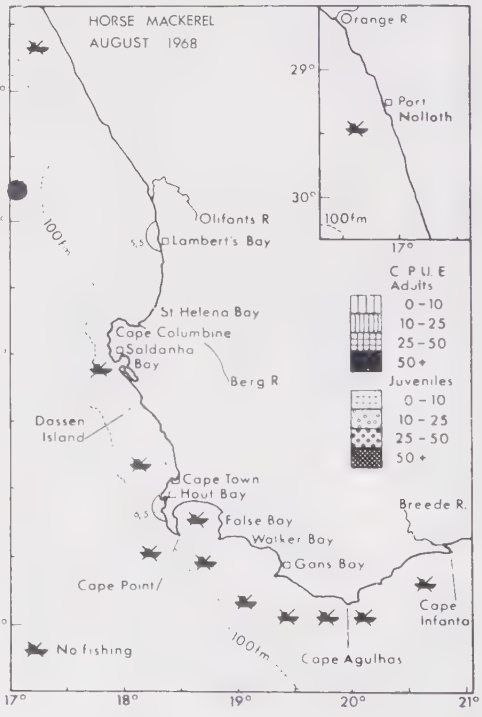
HORSE MACKEREL
AUGUST 1968
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Port Nolloth
Olifants R
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St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
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Hout Bay
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No fishing
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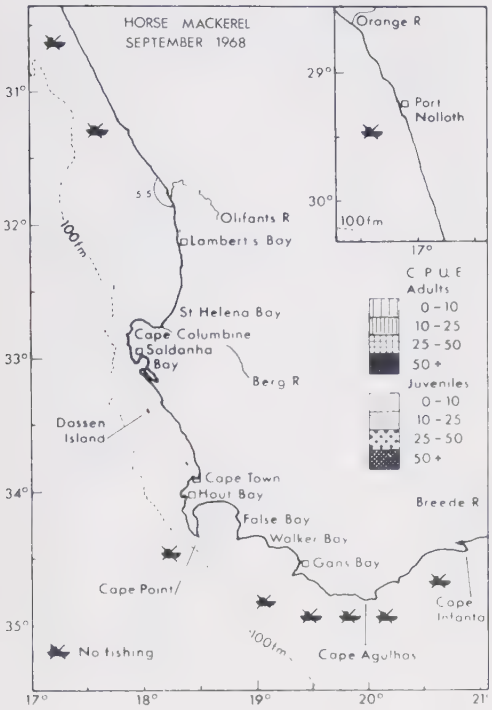
HORSE MACKEREL
SEPTEMBER 1968
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100fm
17°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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Juveniles
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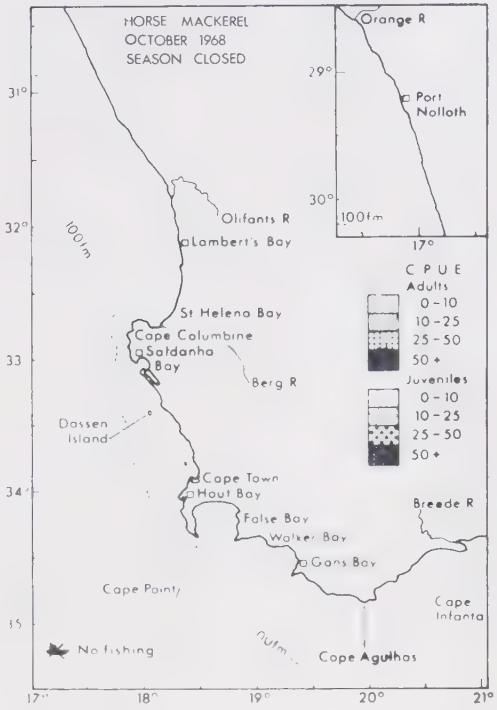
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OCTOBER 1968
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St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
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Cape Point
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No fishing
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Adults
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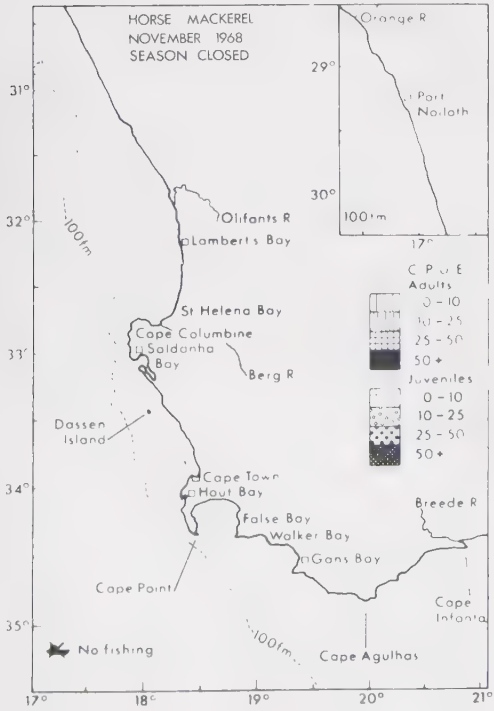
HORSE MACKEREL
NOVEMBER 1968
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
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Juveniles
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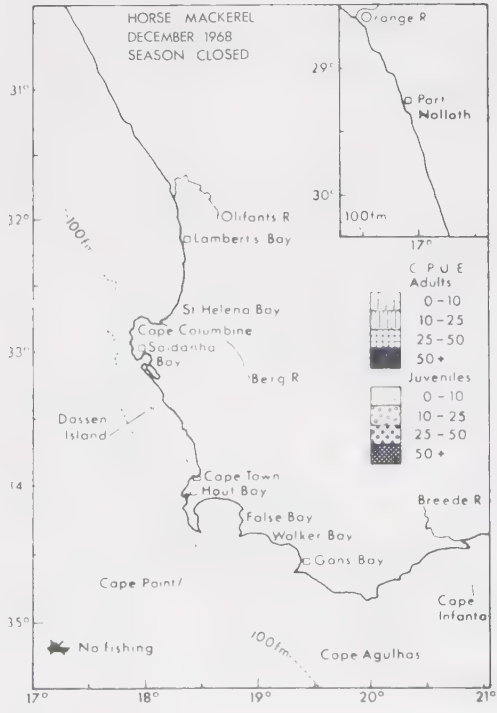
HORSE MACKEREL
DECEMBER 1968
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Port Nolloth
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Lambert's Bay
St Helena Bay
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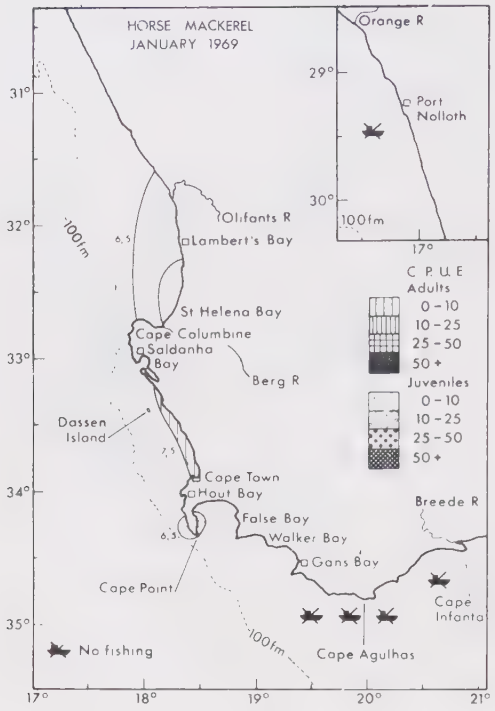
HORSE MACKEREL
JANUARY 1969
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Port Nolloth
Olifants R
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Cape Columbine
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Dassen Island
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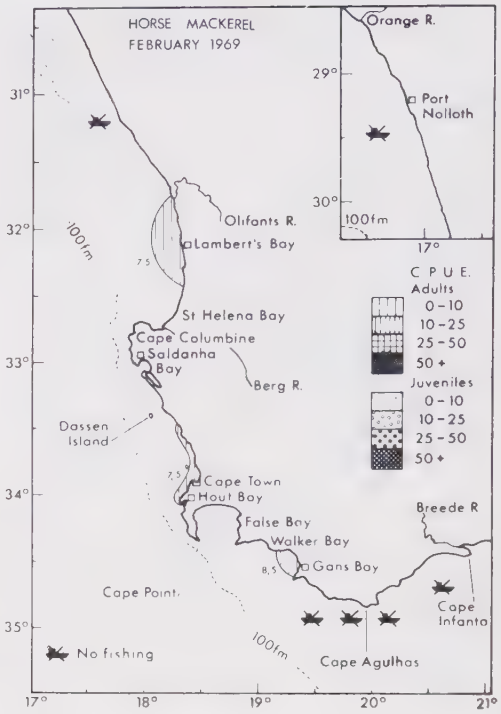
HORSE MACKEREL
FEBRUARY 1969
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Port Nolloth
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St Helena Bay
Cape Columbine
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Berg R.
Dassen Island
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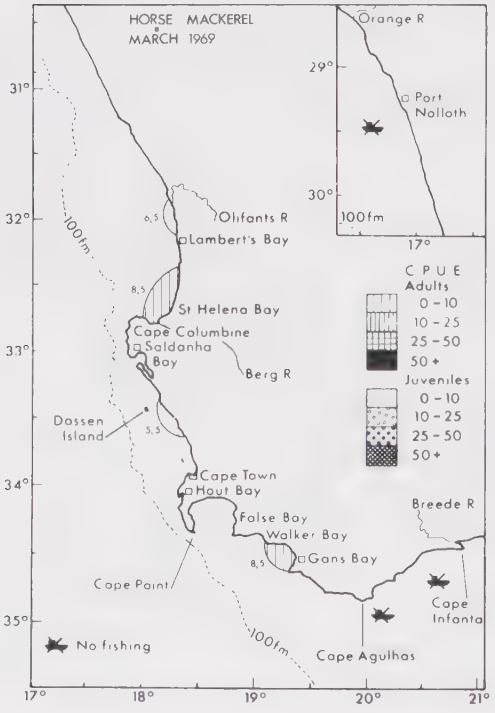
HORSE MACKEREL
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St Helena Bay
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Saldanha Bay
Berg R
Dassen Island
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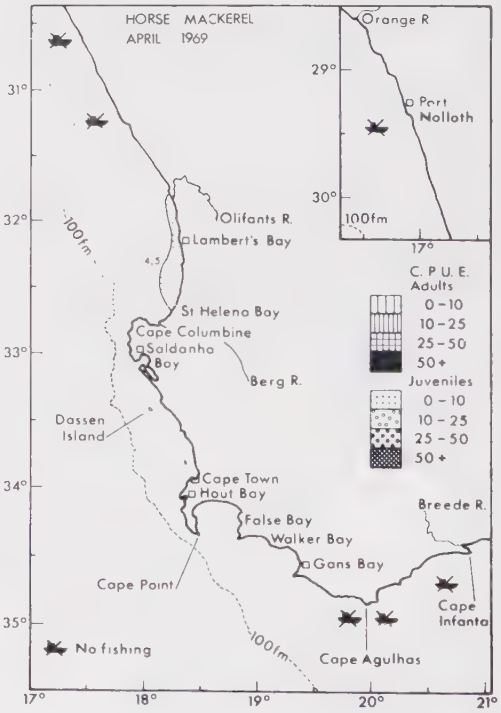
HORSE MACKEREL
APRIL 1969
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Cape Columbine
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Juveniles
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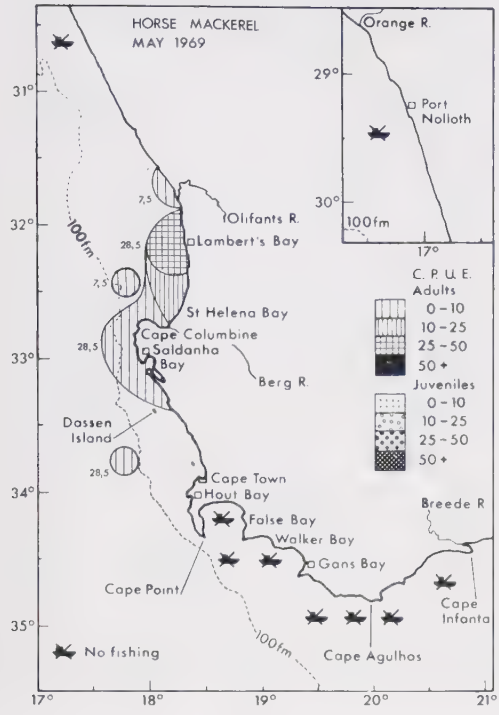
HORSE MACKEREL
MAY 1969
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Port Nolloth
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Berg R.
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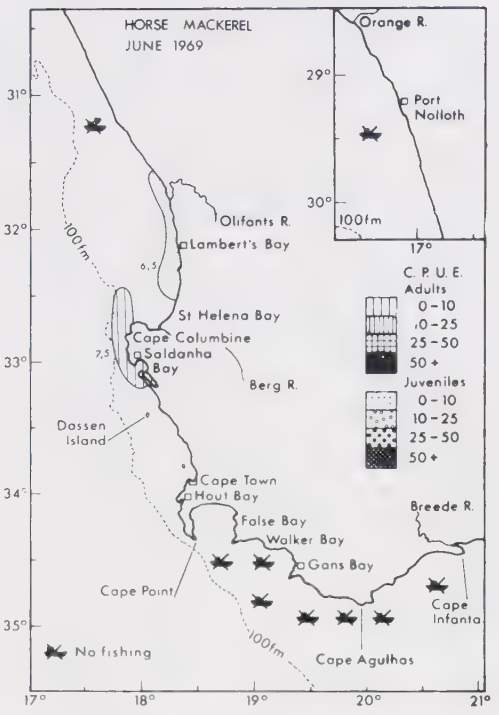
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JUNE 1969
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Berg R.
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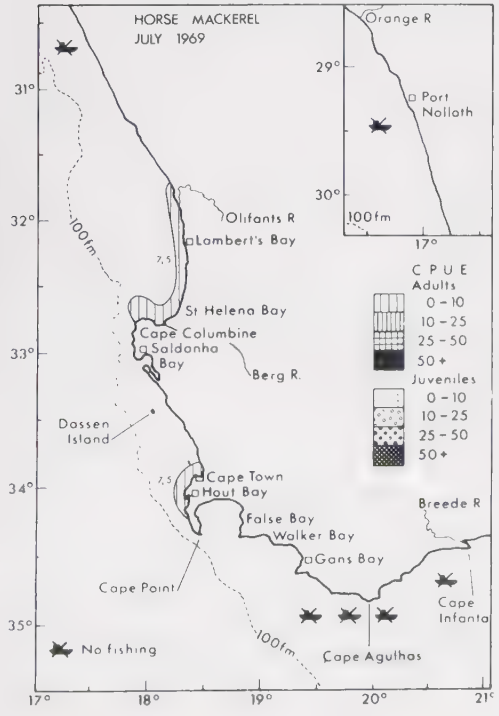
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JULY 1969
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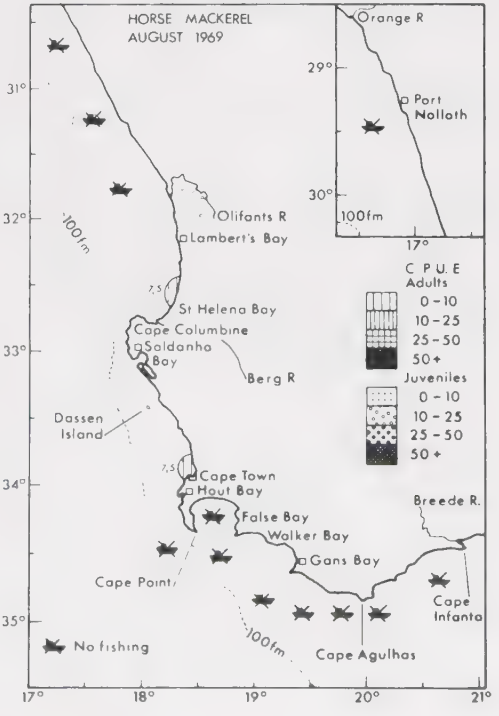
HORSE MACKEREL
AUGUST 1969
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Berg R
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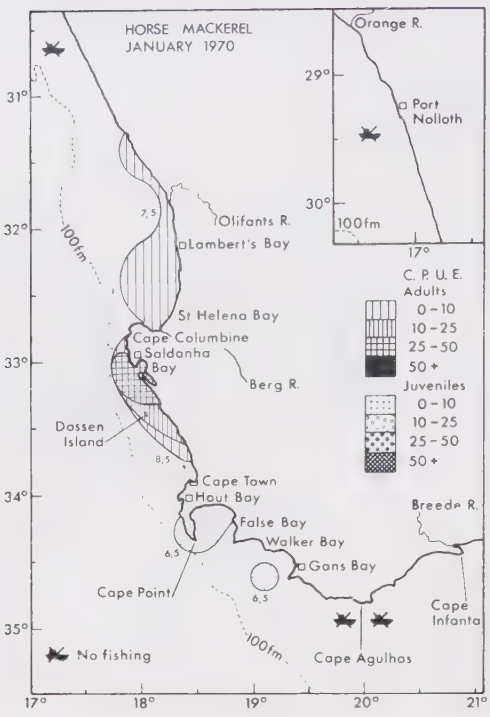
HORSE MACKEREL
JANUARY 1970
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Lambert's Bay
St Helena Bay
Cape Columbine
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Berg R.
Dassen Island
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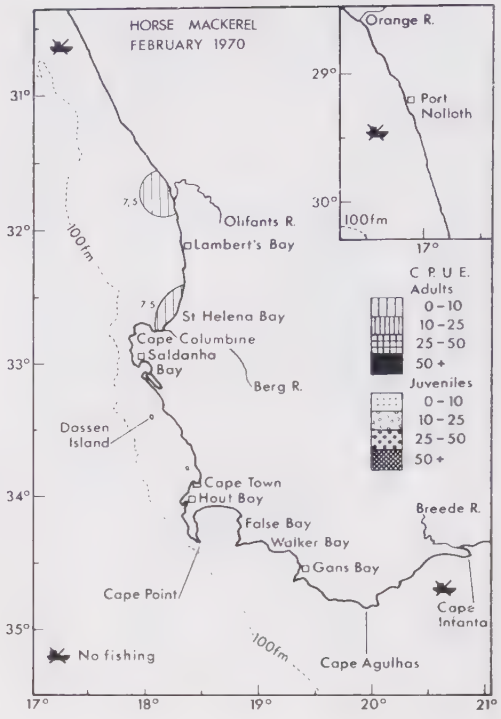
HORSE MACKEREL
FEBRUARY 1970
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
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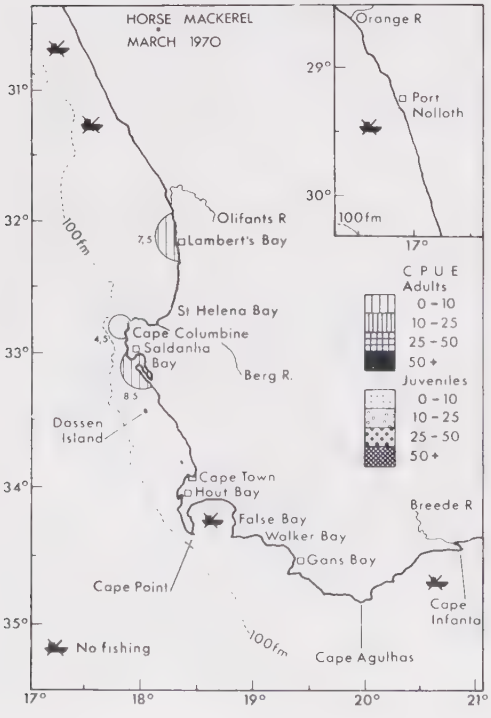
HORSE MACKEREL
MARCH 1970
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100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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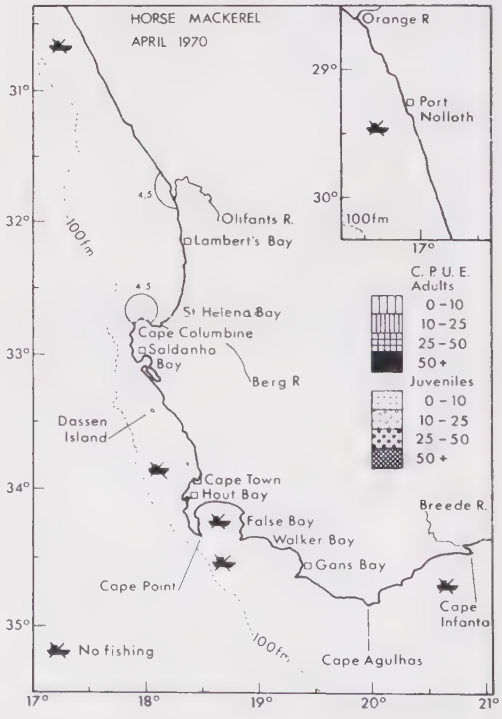
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Dassen Island
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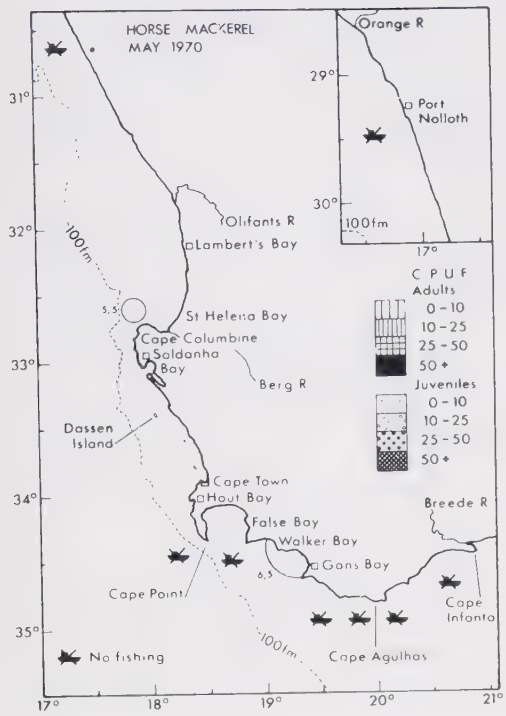
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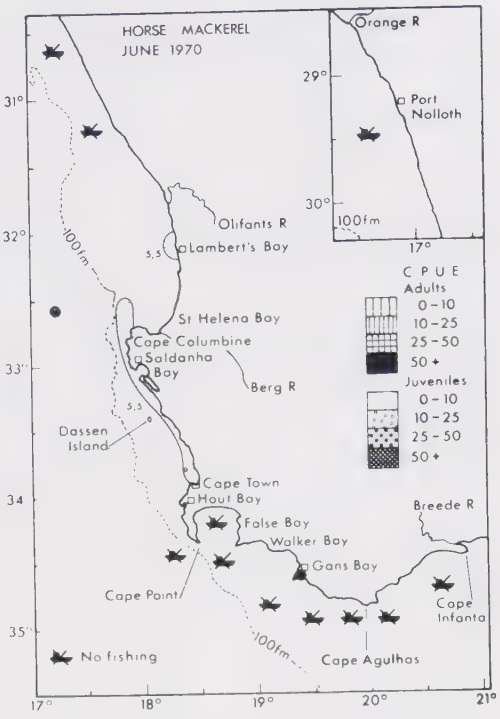
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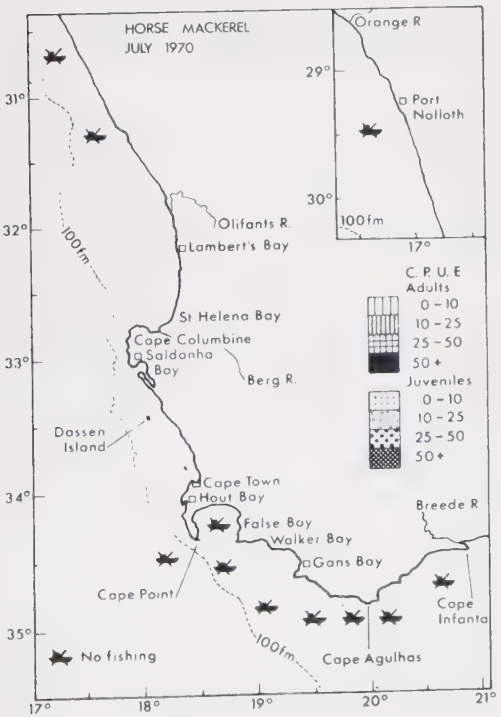
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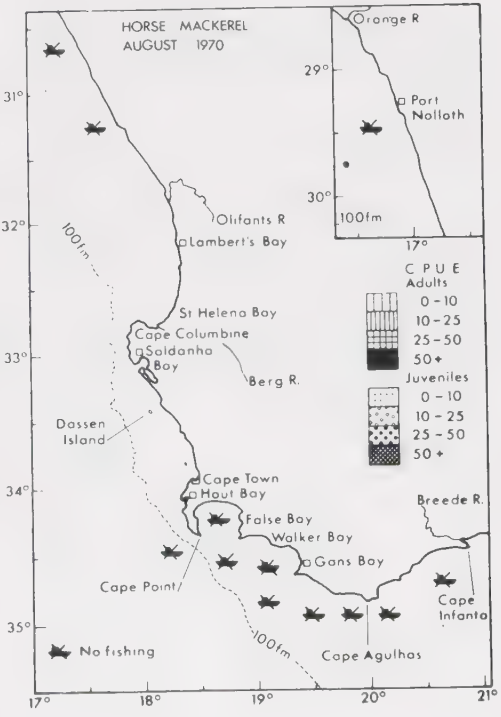
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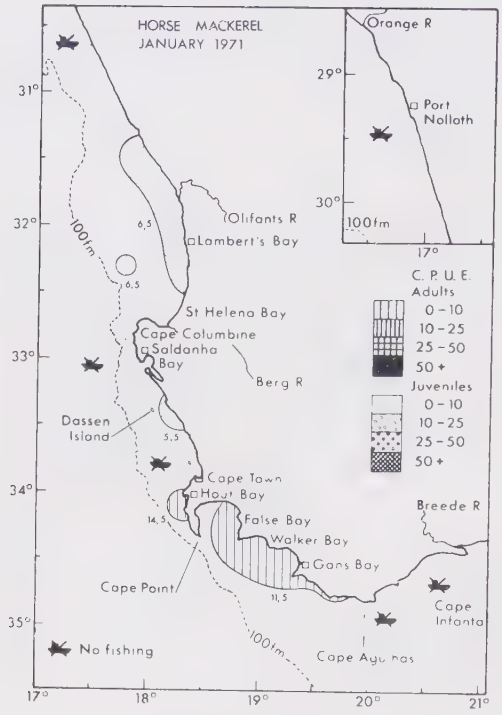
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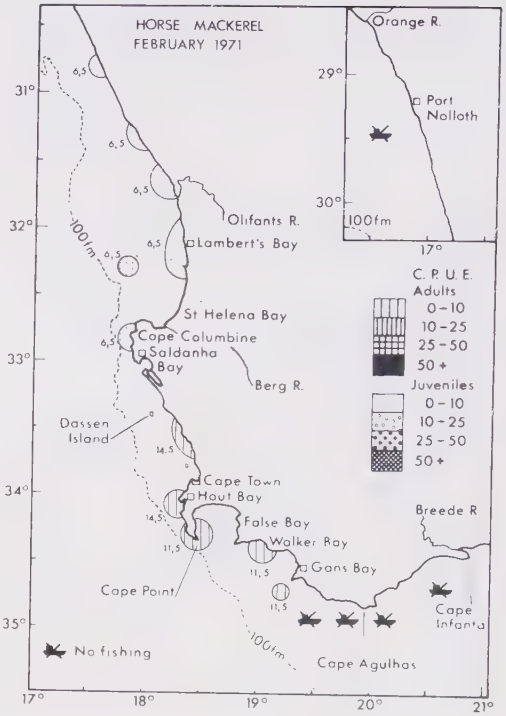
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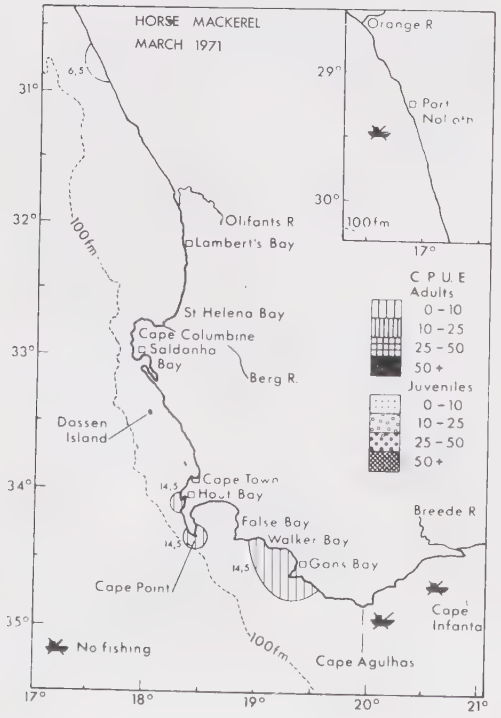
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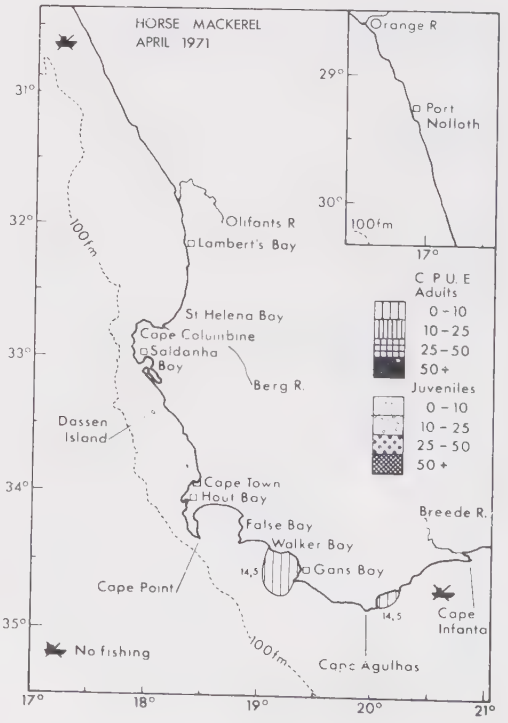
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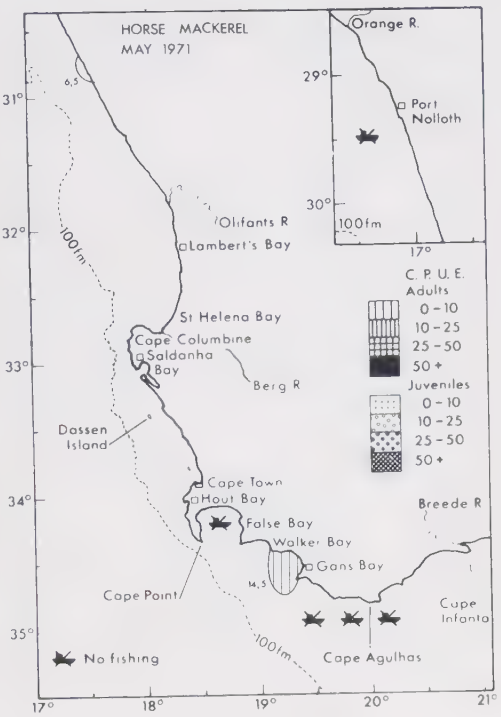
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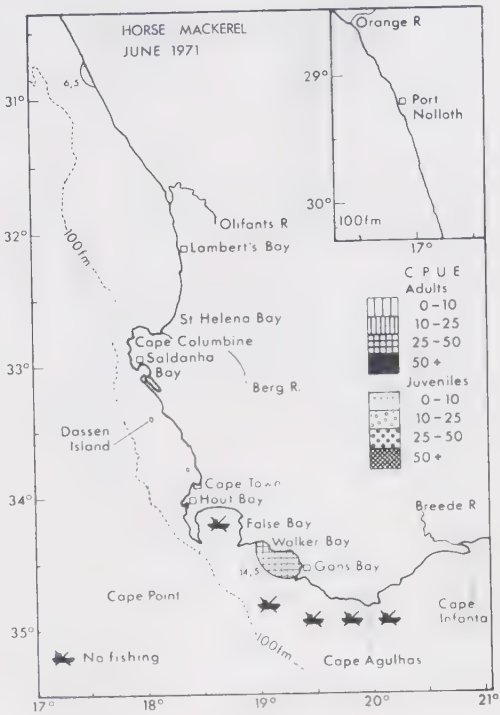
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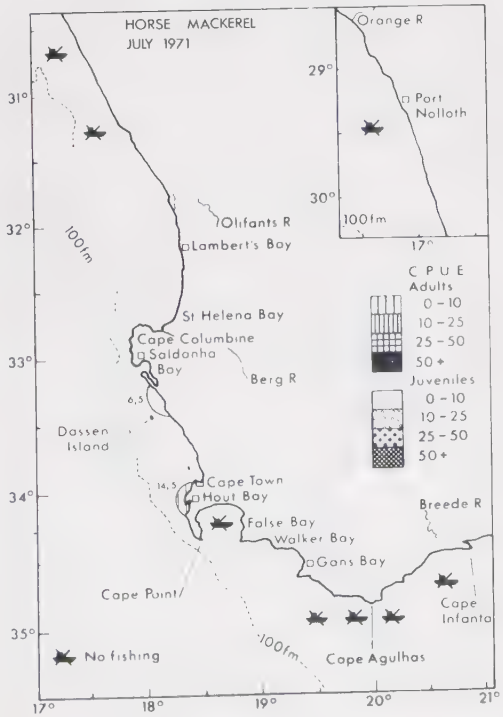
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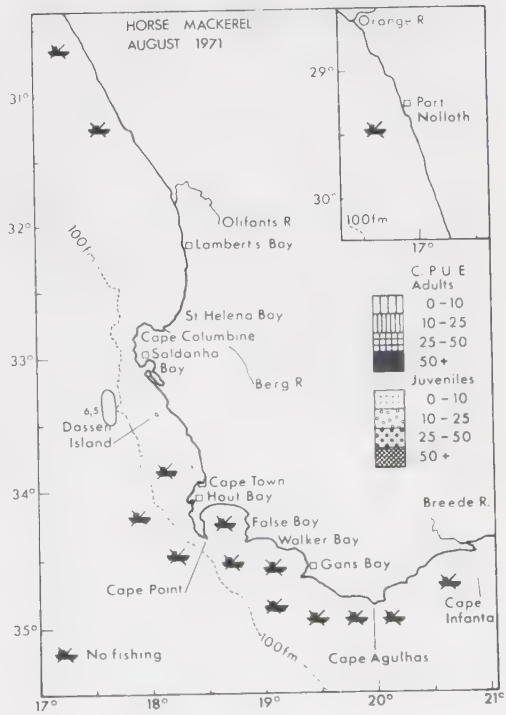
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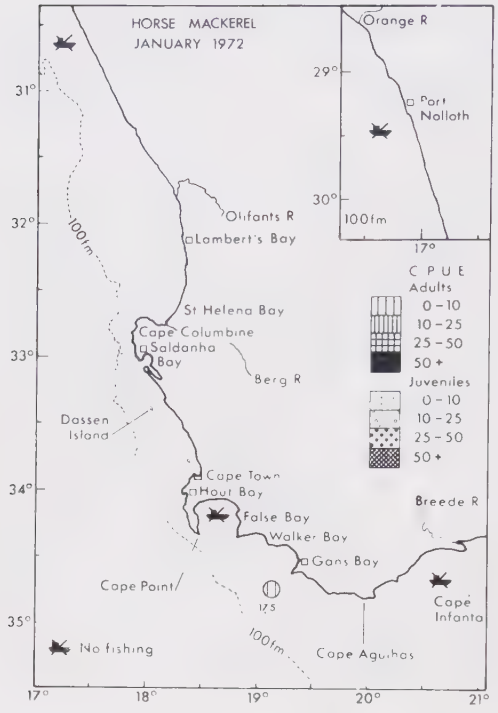
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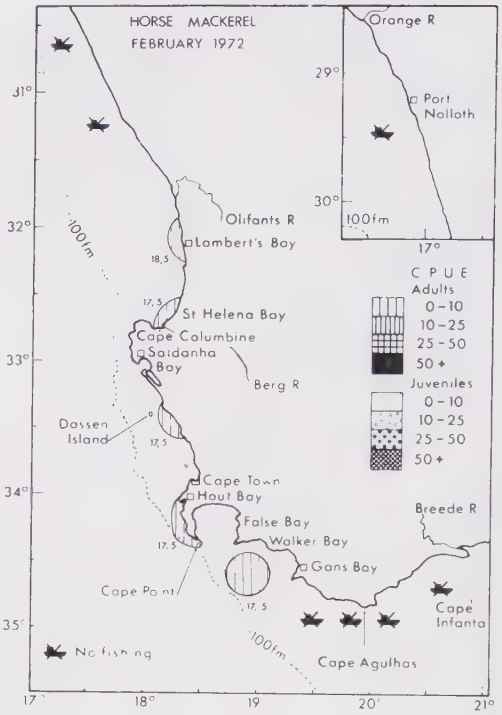
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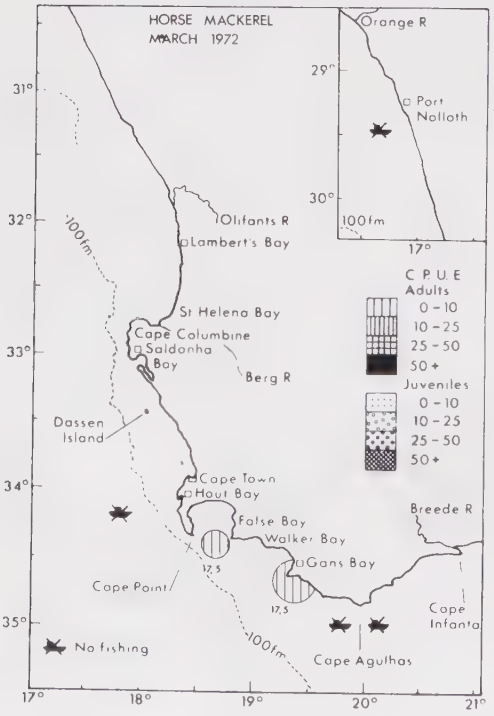
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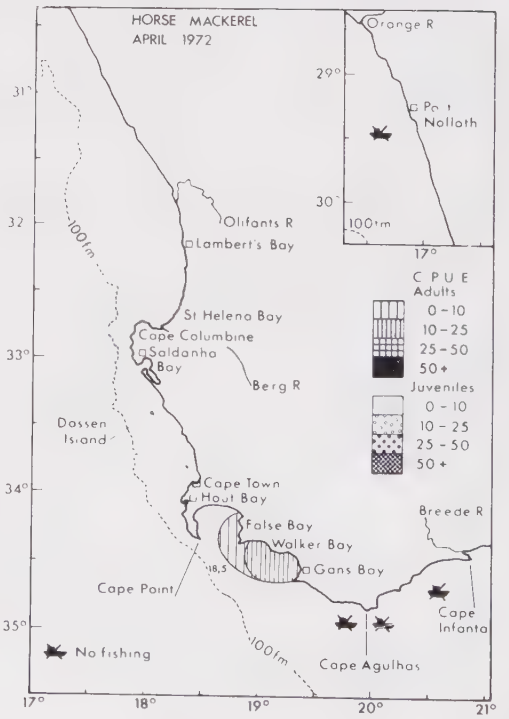
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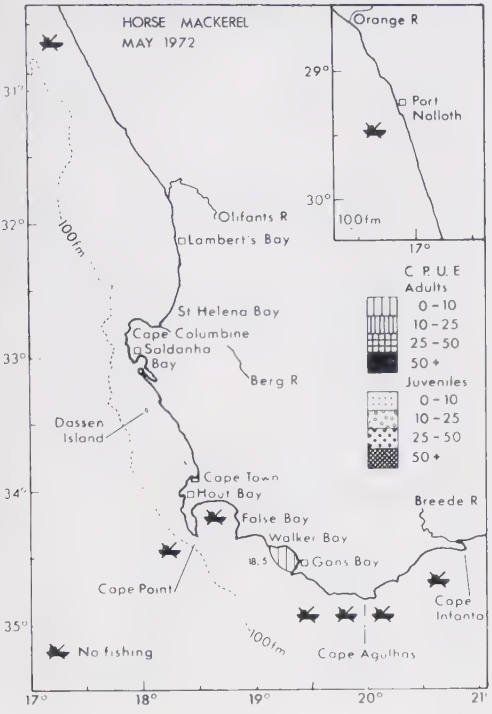
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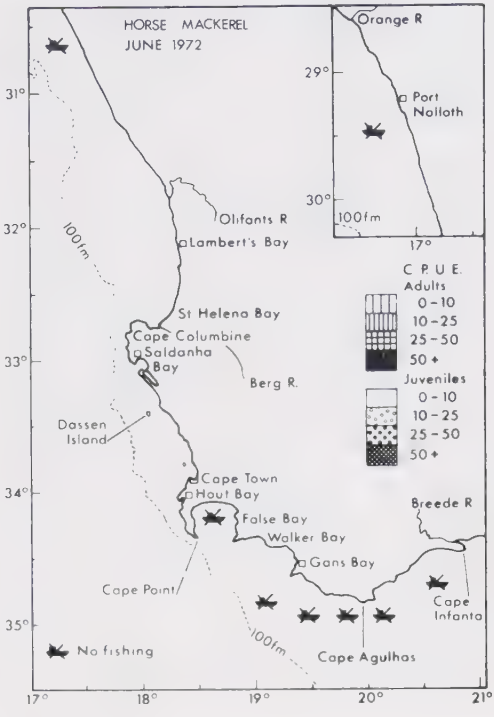
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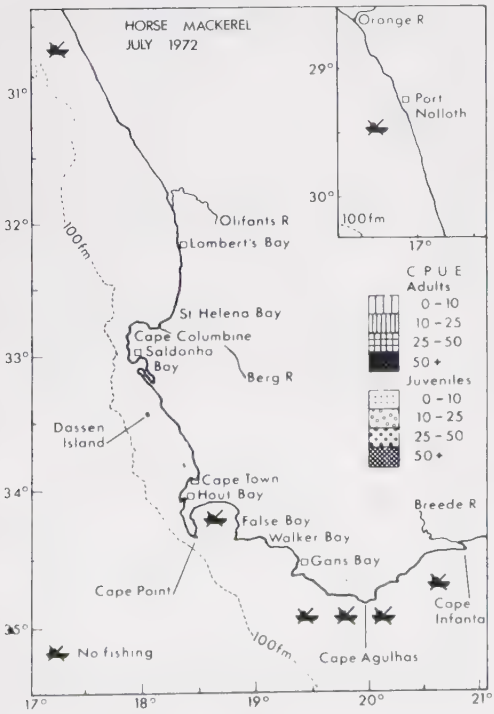
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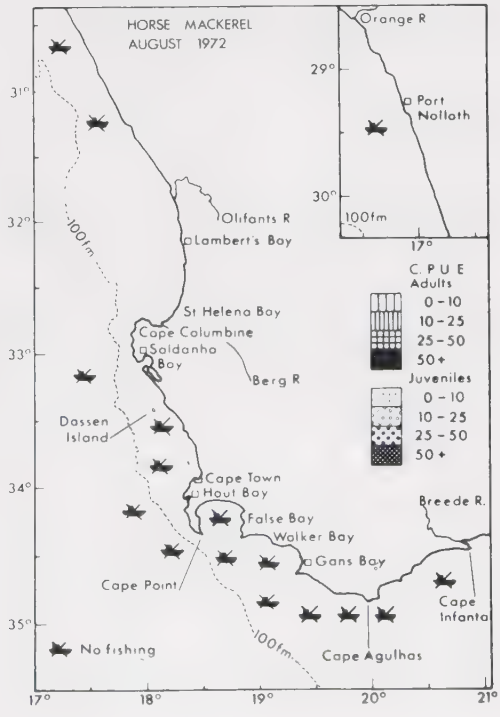
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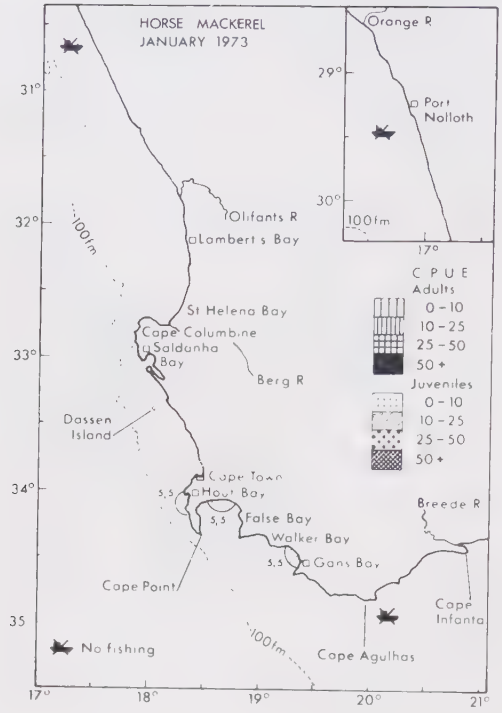
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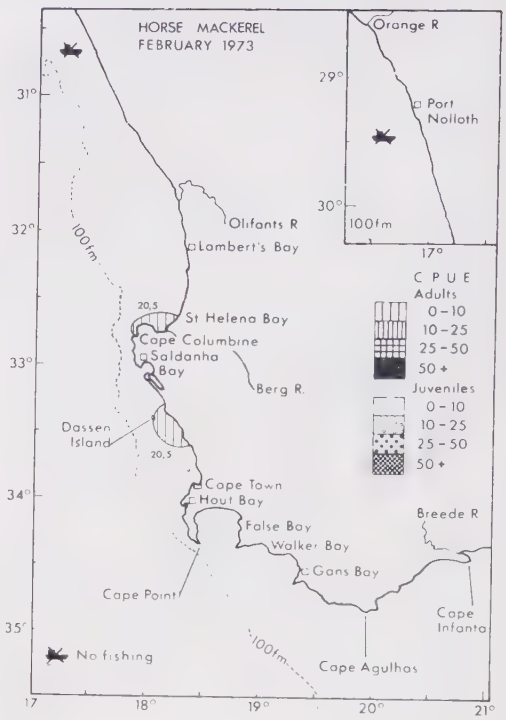
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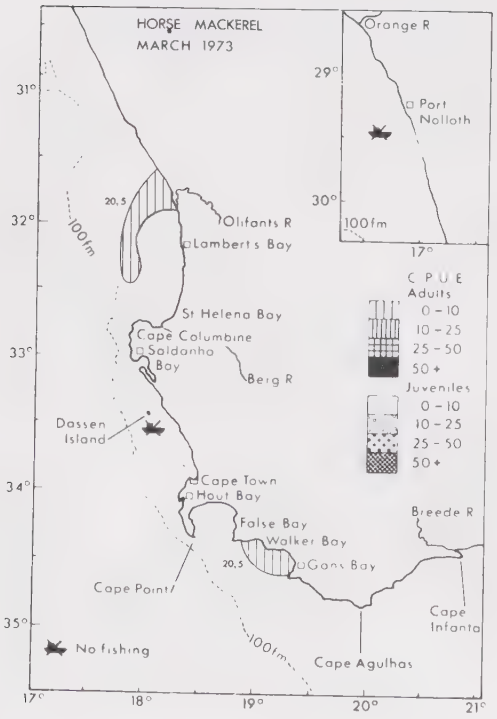
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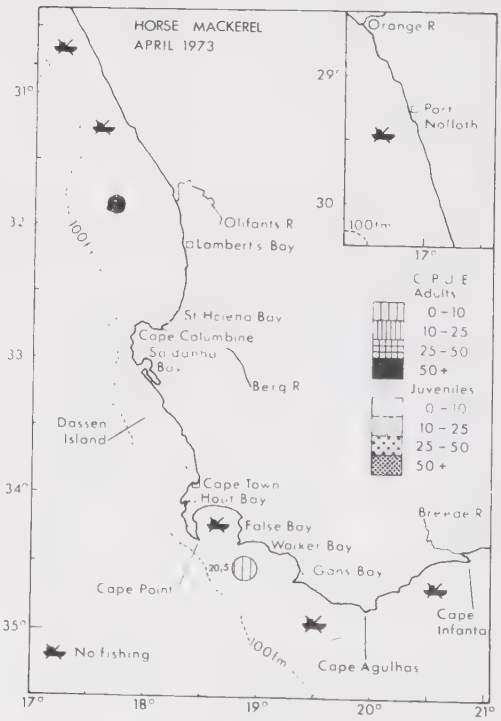
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St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
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Juveniles
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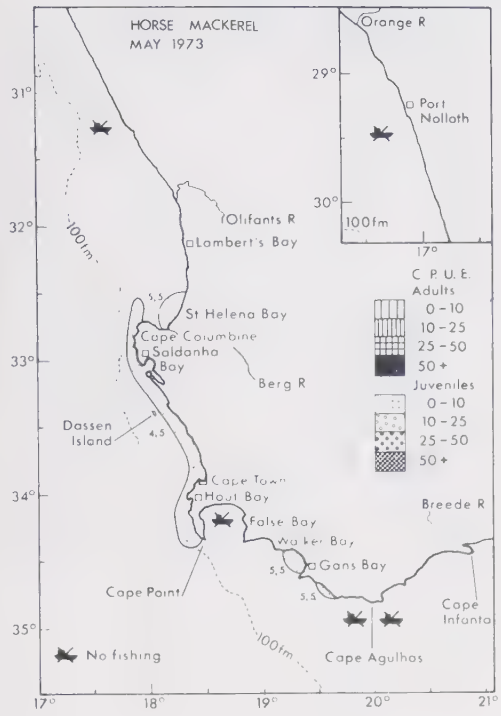
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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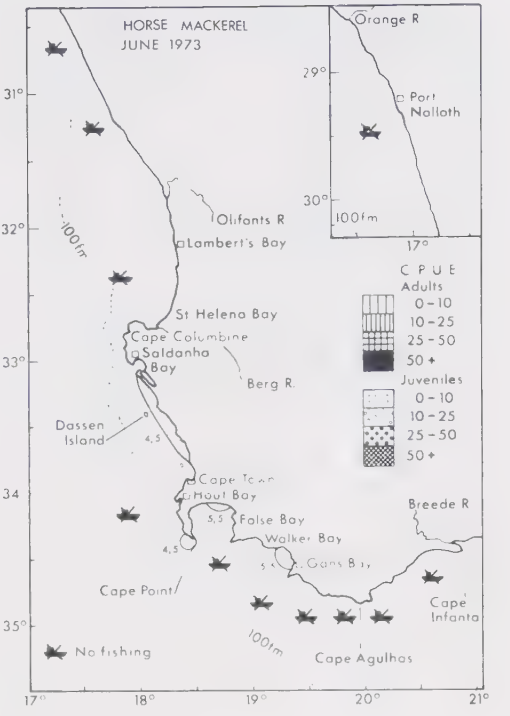
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Berg R
Dassen Island
Cape Town
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Cape Infanta
Cape Agulhas
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Juveniles
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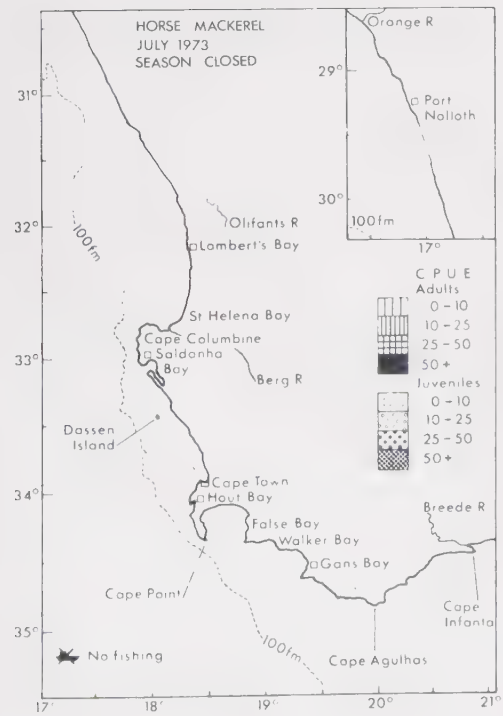
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Berg R
Dassen Island
Cape Town
Hout Bay
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Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Adults
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Juveniles
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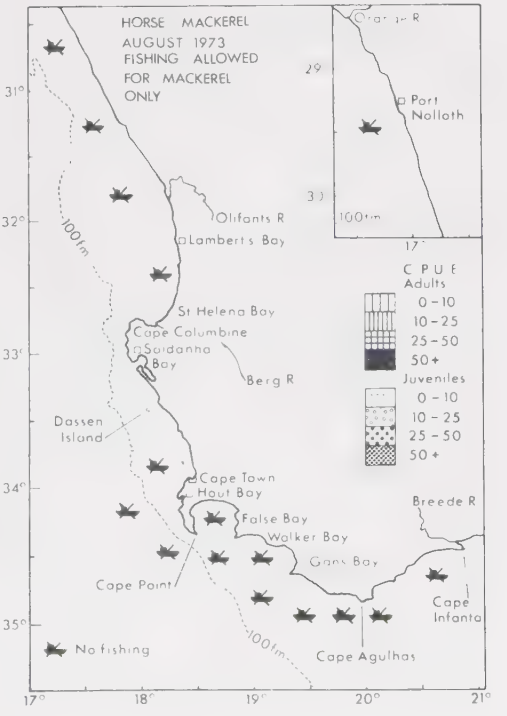
HORSE MACKEREL
AUGUST 1973
FISHING ALLOWED
FOR MACKEREL
ONLY
Port Nolloth
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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Juveniles
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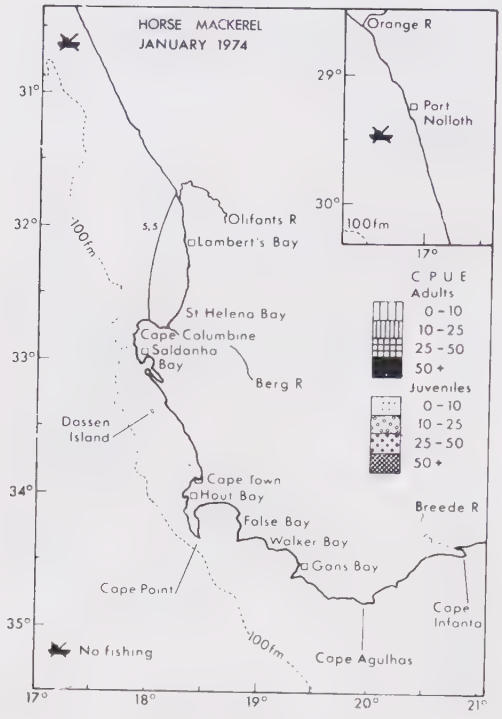
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Dassen Island
Cape Town
Hout Bay
False Bay
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Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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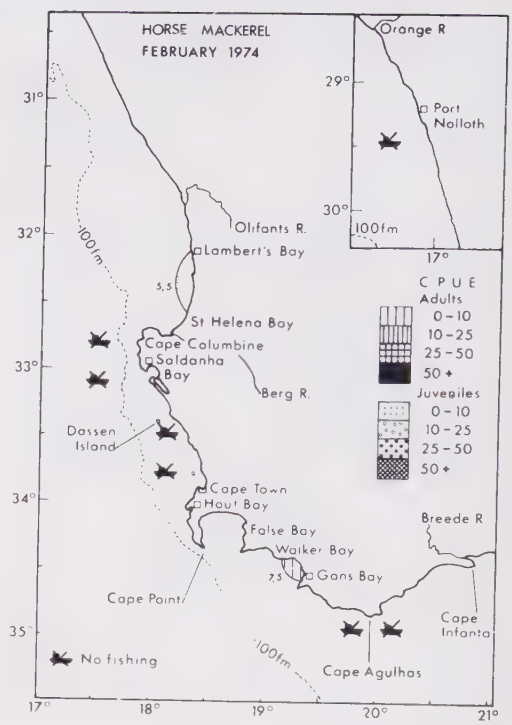
HORSE MACKEREL
FEBRUARY 1974
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Lambert's Bay
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Berg R.
Dassen Island
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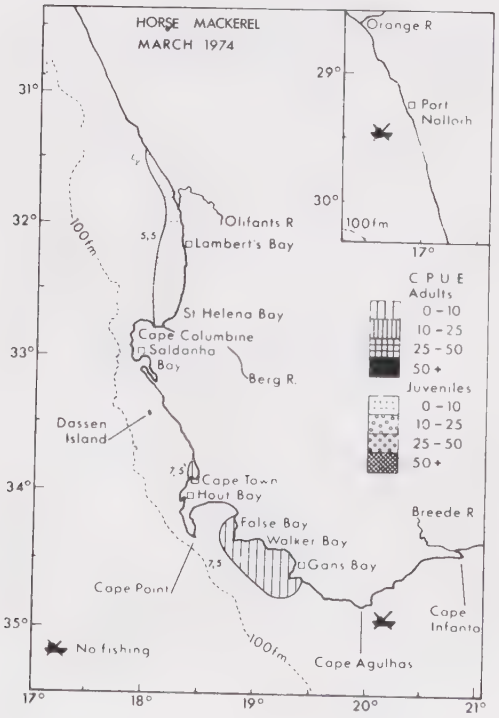
HORSE MACKEREL
MARCH 1974
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Dassen Island
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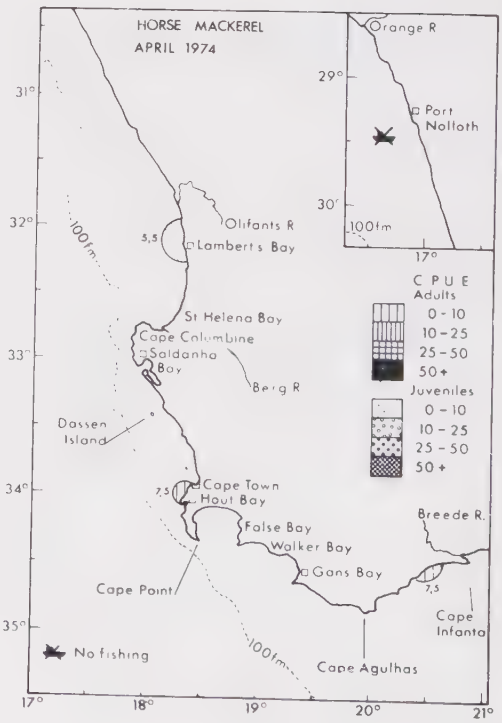
HORSE MACKEREL
APRIL 1974
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Juveniles
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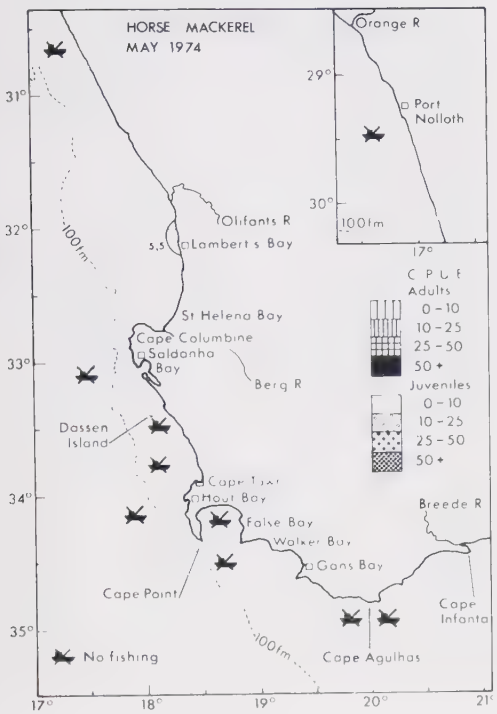
HORSE MACKEREL
MAY 1974
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Juveniles
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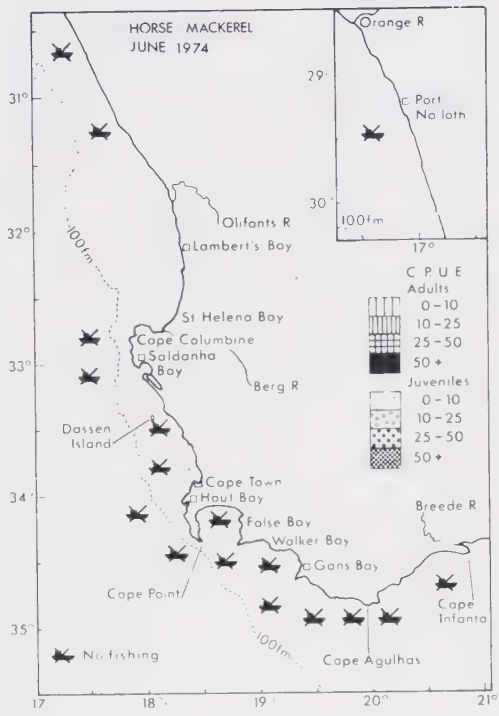
HORSE MACKEREL
JUNE 1974
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Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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No fishing
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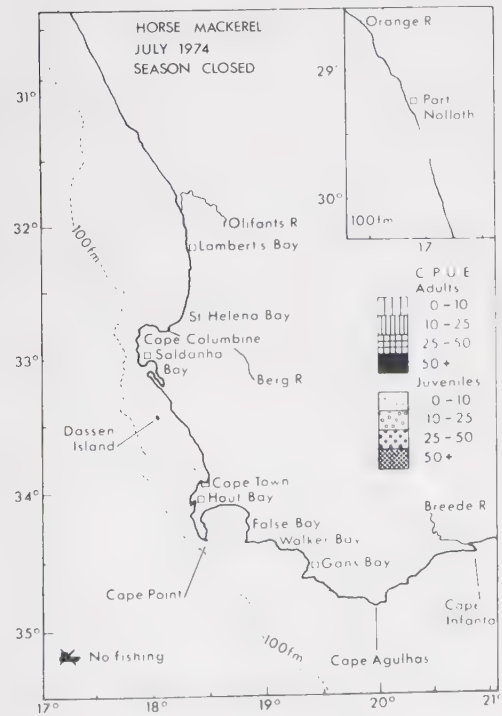
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JULY 1974
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Port Nolloth
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Olifants R
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St Helena Bay
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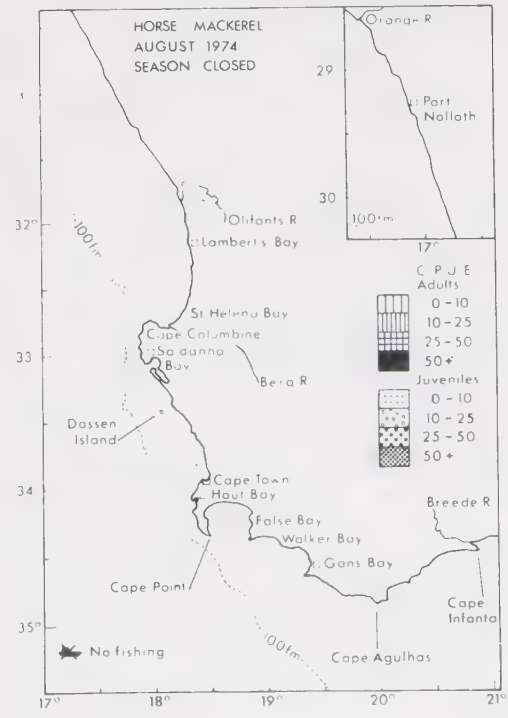
HORSE MACKEREL
AUGUST 1974
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Orange R
Port Nolloth
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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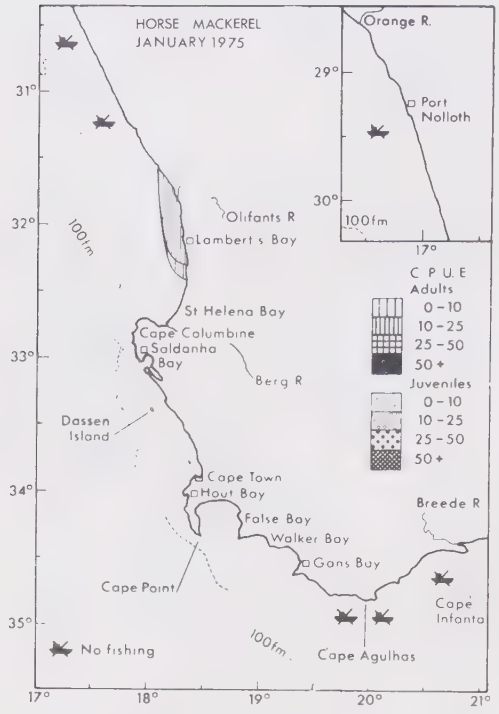
HORSE MACKEREL
JANUARY 1975
Orange R.
Port Nolloth
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Lambert s Bay
St Helena Bay
Cape Columbine
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Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
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Cape Agulhas
No fishing
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Adults
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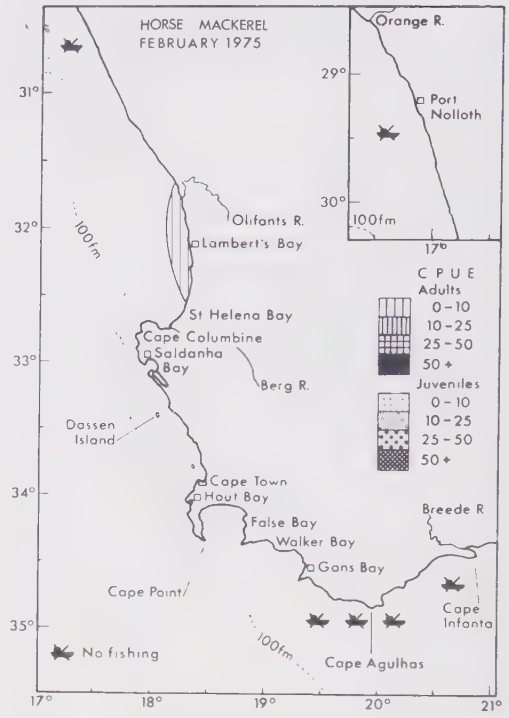
HORSE MACKEREL
FEBRUARY 1975
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Port Nolloth
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St Helena Bay
Cape Columbine
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Berg R.
Dassen Island
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Cape Point
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Cape Agulhas
No fishing
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C P U E
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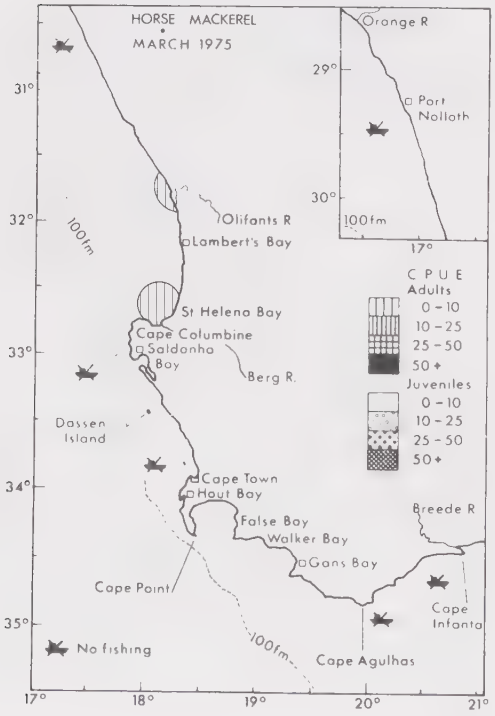
HORSE MACKEREL
MARCH 1975
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Dassen Island
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No fishing
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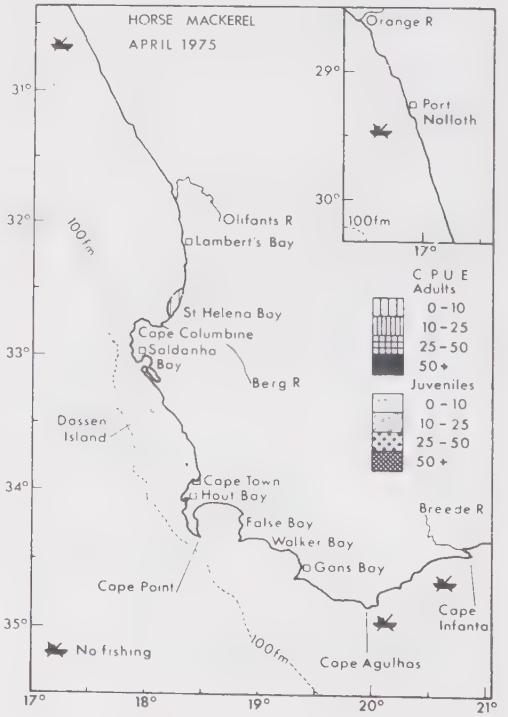
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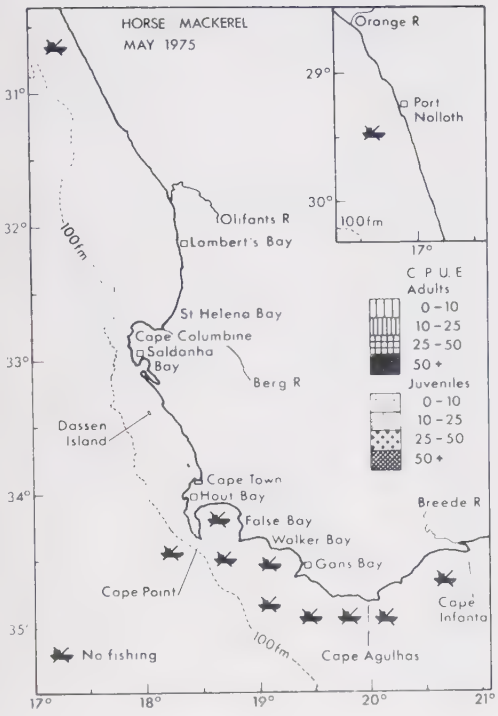
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100fm
C P U E
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Cape Town
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False Bay
Walker Bay
Gans Bay
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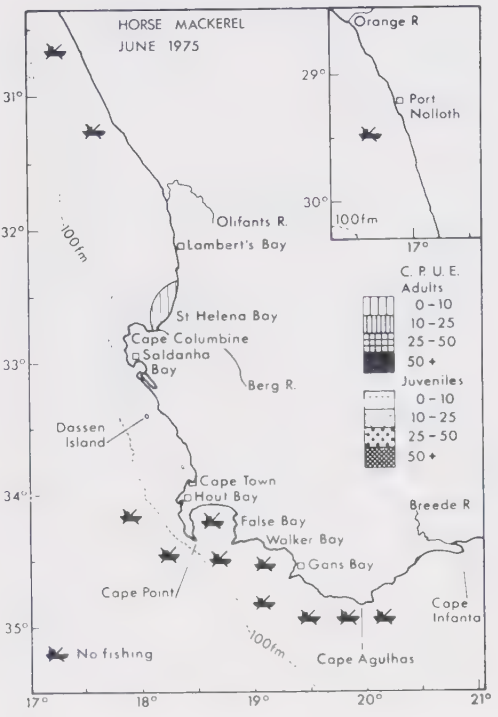
HORSE MACKEREL
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100fm
C. P. U. E.
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Juveniles
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Olifants R.
Lambert's Bay
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Gans Bay
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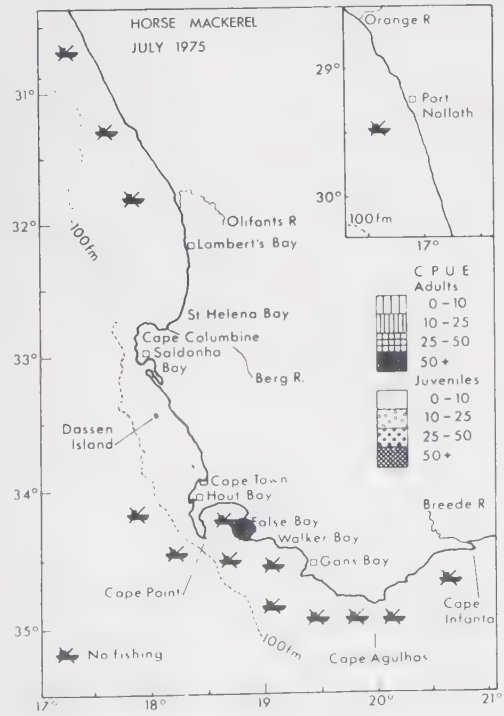
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Olifants R
Lambert's Bay
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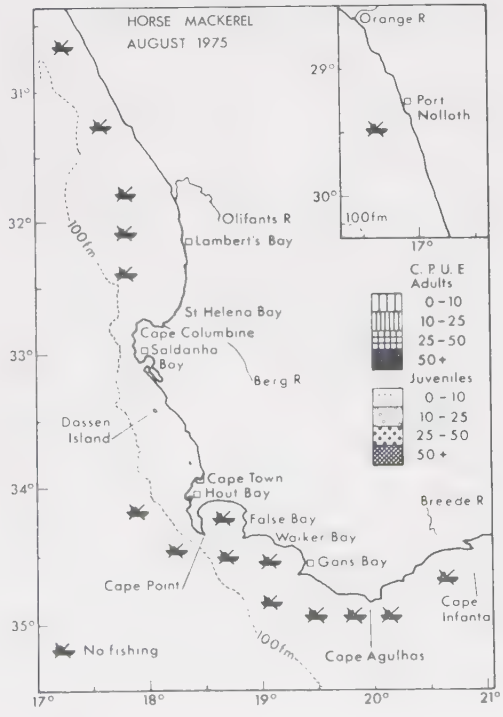
HORSE MACKEREL
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C. P. U. E
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Juveniles
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Olifants R
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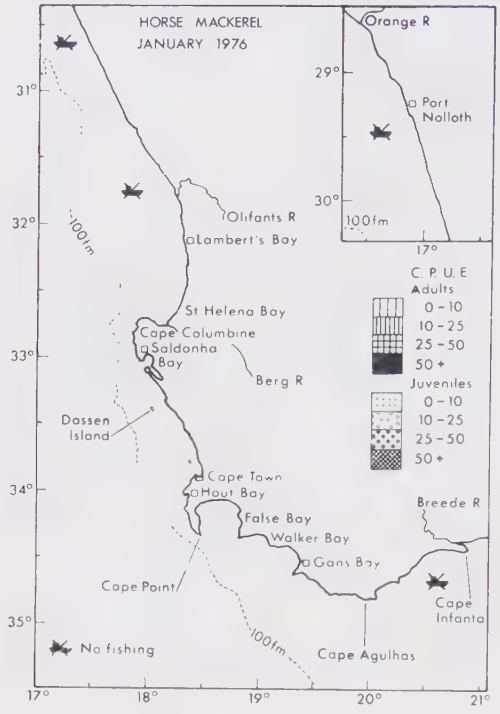
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JANUARY 1976
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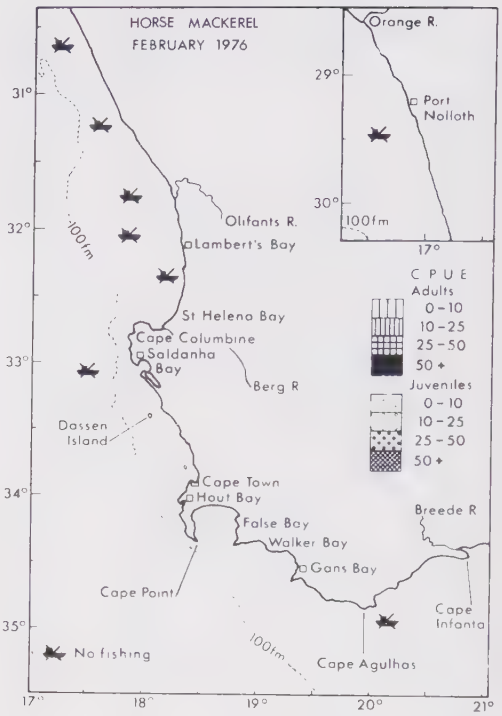
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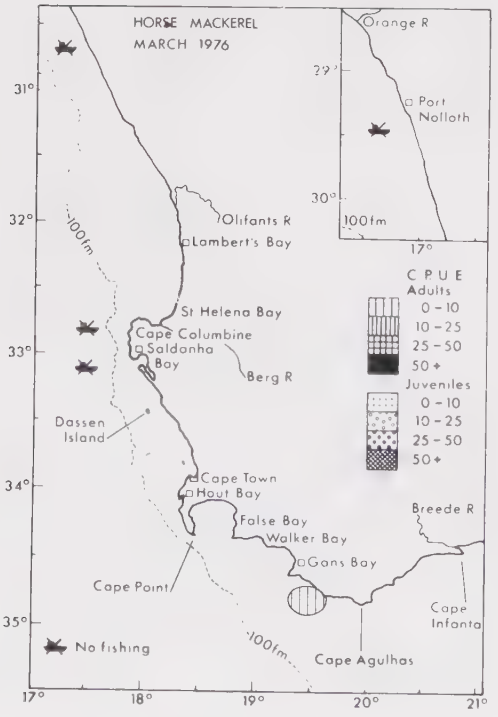
HORSE MACKEREL
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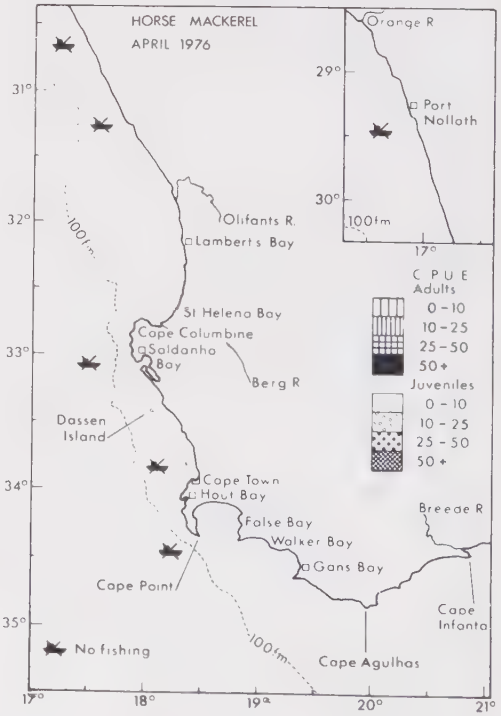
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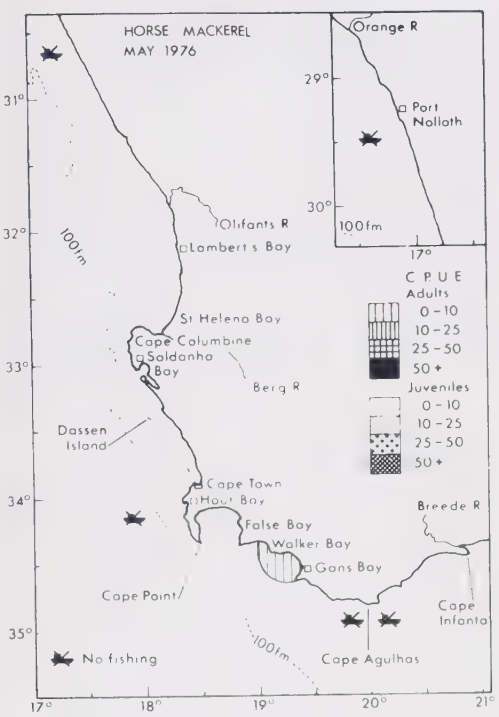
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +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MAY 1976
Orange R
Port Nolloth
29°
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100fm
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32°
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35°
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0-10
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25-50
50+
Juveniles
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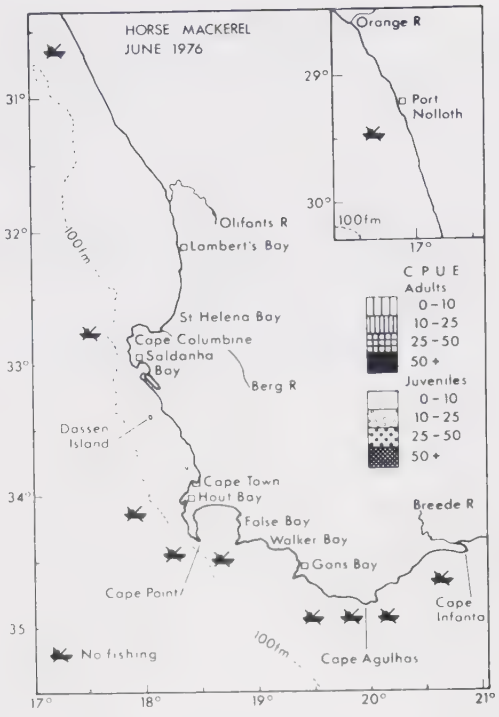
19°
20°
21°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Port Nolloth
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
0-10
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Juveniles
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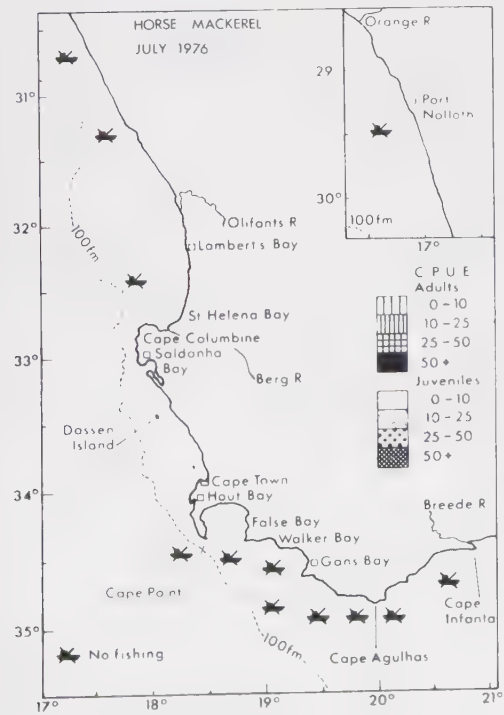
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JULY 1976
Orange R
Port Nolloth
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30°
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100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0-10
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50+
Juveniles
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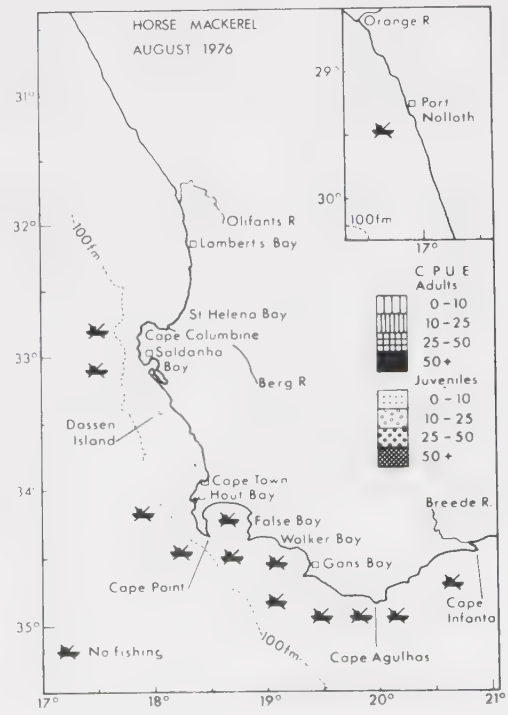
HORSE MACKEREL
AUGUST 1976
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
34°
35°
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0-10
10-25
25-50
50+
Juveniles
0-10
10-25
25-50
50+
17°
18°
19°
20°
21°

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81

A NOTE ON RATE OF EARLY GROWTH OF PILCHARD *SARDINOPS OCELLATA* LARVAE

A.J. BOYD AND A. BADENHORST

The results of sampling pilchard *Sardinops ocellata* eggs and larvae off South West Africa during November and December 1978 are used to calculate a growth rate of young larvae. The determined rate, 0,6 mm per day in 15°C water, is double that of a previously accepted estimate.

Die resultate uit die bemonstering van die larwes en eiers van die sardyn *Sardinops ocellata* langs die kus van Suidwes-Afrika gedurende November en Desember 1978 word gebruik om die groeitempo van jong larwes te bepaal. Die berekende tempo van 0,6 mm per dag in water van 15°C is twee maal soveel as 'n vorige aanvaarde skatting.

A programme of seven extensive ichthyoplankton surveys was conducted during 1978/79 off the South West African coast with the primary intention of sampling eggs and larvae of the pilchard *Sardinops ocellata* and the anchovy *Engraulis capensis*. The programme and methods employed were described by Badenhorst and Boyd (1980), who related the distribution of anchovy larvae to environmental factors. Le Clus and Thomas (1981) and Le Clus and Melo (1981) used the egg data to provide direct estimates of spawning biomass. Fortuitous timing of one of the cruises during the 1978/79 survey made an accurate estimate of the rate of early growth of the South West African pilchard possible.

O'Toole (1977) presented estimated growth rates of pilchard larvae and discussed the difficulties inherent in tracing larval cohorts in successive months. In the present study, the data enabled some of the problems to be avoided because a cohort was traced from spawning. This estimate of initial growth rate will enable growth rates calculated by counting day rings on otoliths of larvae, such as has been done by Thomas (1980), to be confirmed by independent means.

SAMPLING METHODS

The grid shown in Figure 1(a) was occupied from October 1978 to April 1979 on a monthly basis. Bongo nets with mesh sizes of 0,300 mm and 0,940 mm were towed for an average of four minutes at two knots between the surface and 50 m, and limited environmental sampling was carried out at each station. Numbers of eggs and larvae caught were standardized to the number under 10 m^2 of sea surface, and standard (caudal) lengths were measured to the nearest millimetre below.

Table I: Numbers of pilchard larvae caught during different months

Month	1972/73 survey (from O'Toole 1977)	1973/74 survey (from O'Toole 1977)	1978/79 survey
August	2	7	—
September	668	96	—
October	50	154	6
November	64	175	0
December	8	11	2 083
January	48	1 670	1 362
February	65	538	147
March	81	—	4 836
March/April	—	6 414	—
April	—	—	748

RESULTS AND DISCUSSION

Previous work on the spawning and larval occurrence of the South West African pilchard (Stander 1963, Matthews 1964, King 1977a and O'Toole 1977) has shown that spawning tends to occur under two temperature regimes: cool-water spawning in winter/spring, and warm-water spawning in summer/autumn. Minimum spawning and larval occurrence between these two spawnings were noted by all the above authors except King (*op. cit.*). The monthly numbers of pilchard larvae taken by O'Toole (*op. cit.*) during his surveys in 1972/73 and 1973/74 and on the 1978/79 survey are shown in Table I. Different mesh sizes and extensions to the grid preclude direct comparison of numbers between the different surveys.

A minimum abundance of larvae was recorded in December of both 1972 and 1973, falling between the winter/spring and summer/autumn

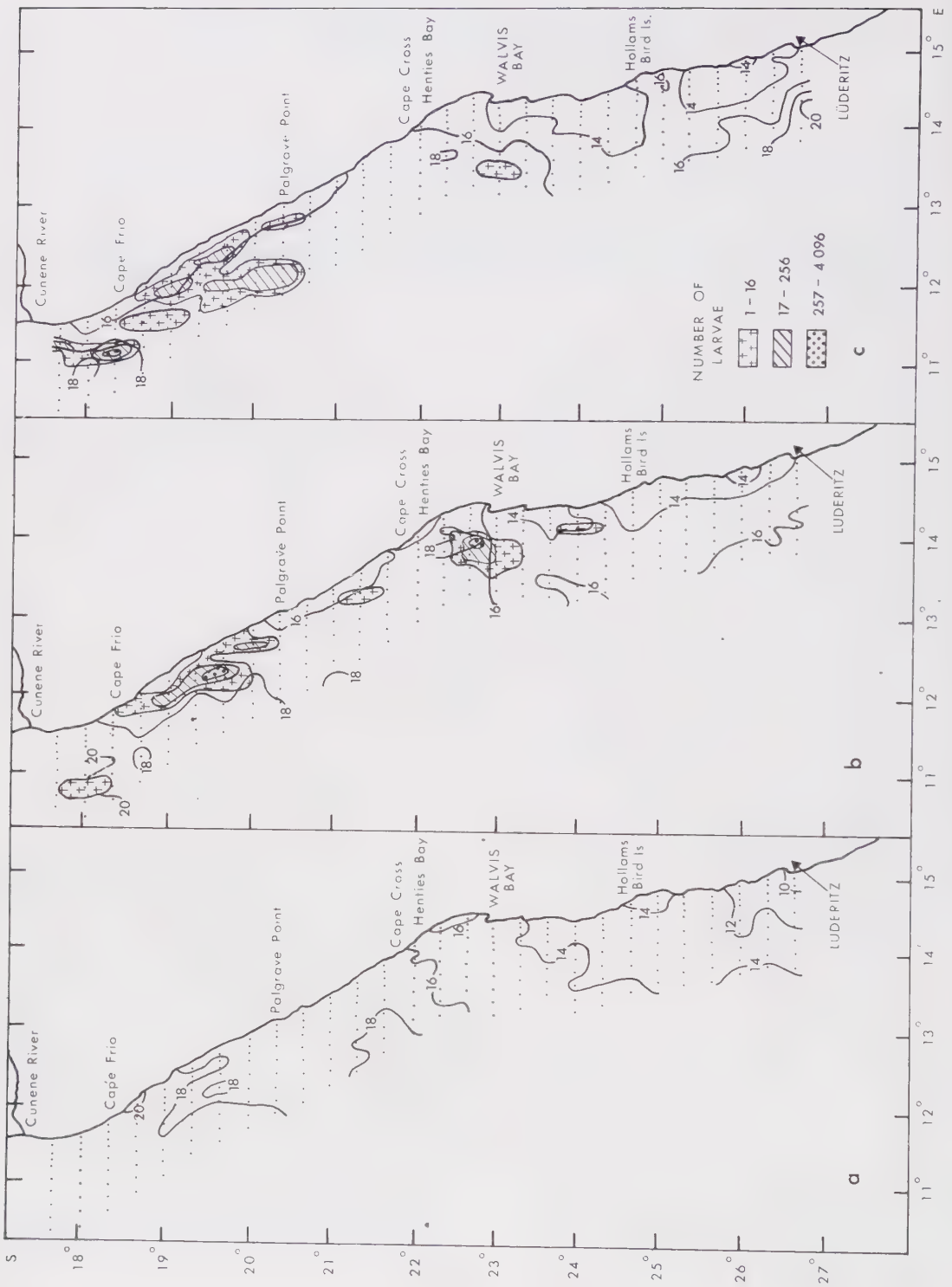

Fig. 1: (a) The 1978/79 survey grid and the distributions of temperature and larvae in November 1978, (b) in December 1978, (c) in January 1979

axima (Table I). No such minimum was recorded ring the 1978/79 survey and also, because no mpling was undertaken in August or September, similar peak in winter/spring larval abundance as noted. It is also possible that, in 1978, very tle winter/spring spawning actually occurred. owever, larvae were scarce or absent in October d November (before the summer/autumn awning season) in the 1978/79 survey, and this servation could correspond to the early summer inimum of O'Toole (1977).

In November 1978, temperatures were substantially higher than in October, especially north Cape Cross (Fig. 1a). In this area a cessation of astal upwelling had allowed warm water to trude from the north (Badenhorst and Boyd 980). Over much of the survey area, pilchard gs were more abundant than during the previous onth (Le Clus and Thomas 1981). Following the nclusions of King (1977a), who classified pilchard awning north of Cape Cross as "warm water offore" spawning, this intrusion appears to have en responsible for the onset of the spawning in is area. The fact that no pilchard larvae were mpled with these eggs implies that the bulk of awning coincided with the northward progression the research vessel conducting the cruise.

King (1977b), working under artificially conolled conditions in the laboratory, found that chard eggs took about 2 days to hatch in 14-°C water, and 1½ days in 17-18°C water. The ngth at hatching ranged from 3,30 to 3,80 mm. the basis of the length-frequency information sented in Table II, which shows many preserved vae in the 2-3 mm range, a length at hatching of 5 mm was accepted for preserved larvae collected ring the present survey. The surface temperares in the northern area in November 1978 were 19°C (Fig. 1b), and temperatures at 20 m were out 2°C lower. Therefore the pilchard eggs uld have taken about 1—2 days to hatch in ovember 1978 if the laboratory results of King *p. cit.)* apply in the natural environment.

During December 1978, two major patches of rvae were detected: one patch off Walvis Bay hich consisted of small larvae, 2-5 mm long, and more extensive patch between Cape Frio and algrave Point (Fig. 1b). The latter patch was in ater with the surface temperature ranging from 6 to 18°C, and it consisted of two length groups Table II). The larger length group had a well-efined modal peak at 11,5 mm, and it is concluded hat these larvae were the survivors of November pawning in the same area. This conclusion may e justified on the basis of the evidence given regarding:

(i) the absence of larvae (of any size) in November 1978,
(ii) the abundance of pilchard eggs in November 1978,
(iii) the documented occurrences of a break between winter/spring and summer/autumn spawning.

Table II: Monthly length-frequency distribution of pilchard larvae, 1978/79

Length group (mm)	October		December		January	
	Number	%	Number	%	Number	%
1—2			4	0,2		
2—3			663	31,8		
3—4			452	21,7		
4—5			359	17,2	226	16,6
5—6			234	11,2	61	4,5
6—7			72	3,5	60	4.4
7—8			4	0,2	156	11,5
8—9					131	9,6
9—10			28	1,3	34	2,5
10—11	6	100	32	1,5	23	1,7
11—12			109	5,2	45	3,3
12—13			45	2,2	19	1,4
13—14			15	0,7	30	2,2
14—15			36	1,7	44	3,2
15—16			8	0,4	59	4,3
16—17					44	3,2
17—18			5	0,2	54	4,0
18—19			4	0,2	35	2,6
19—20			4	0,2	24	1,8
20—21					57	4,2
21—22					28	2,1
22—23					31	2,3
23—24			9	0,4	70	5,1
24—25					47	3,5
25—26					51	3,7
26—27					14	1,0
27—28					15	1,1
28—29					4	0,3
29—30					0	

Around 20°S, larval drift would have been slightly southward during November (Badenhorst and Boyd 1980, Fig. 1a). However, a measure of coastal upwelling in December (Fig. 1b) would have caused a slightly northward and off-shore drift. These opposing trends suggest that no allowance need be made for larval drift. Also, water temperatures 20 m deep were generally about 2°C lower than at the surface. This factor will be taken into account when presenting growth rates, O'Toole (1977) also favouring the 20-m depth in relating pilchard larvae to the temperature environment.

During November and December 1978, the R.S.

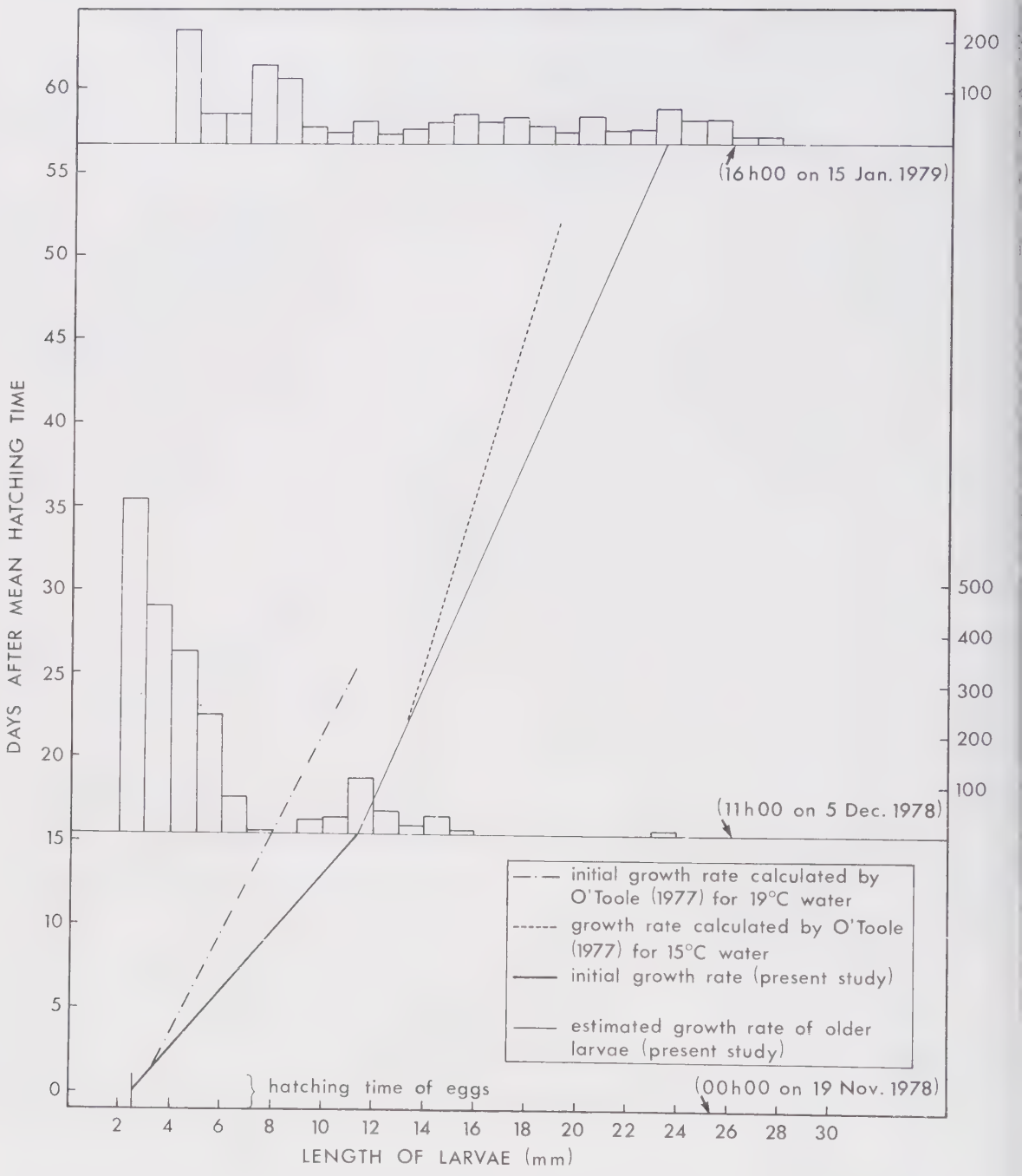
DAYS AFTER MEAN HATCHING TIME
LENGTH OF LARVAE (mm)
(16 h00 on 15 Jan. 1979)
(11 h00 on 5 Dec. 1978)
(00 h00 on 19 Nov. 1978)
hatching time of eggs
initial growth rate calculated by O'Toole (1977) for 19°C water
growth rate calculated by O'Toole (1977) for 15°C water
initial growth rate (present study)
estimated growth rate of older larvae (present study)

Fig. 2: Growth rates of pilchard larvae

nguela surveyed the northern sector of the grid m south to north. The inshore station on the °S line was occupied at 00h00 on 19 November, l again at 11h00 on 5 December. Therefore, a riod of 16½ days elapsed between detection of gs in November and of the larger larvae in cember. After the eggs had been sampled in vember they would have hatched within two ys, according to the results of King (1977b), but y could have done so any time after the mpletion of a station. It is assumed that most ched one day after the cohort was originally mpled.

The initial growth rate for pilchard larvae in ter of approximately 15°C (2°C lower than the rface temperature) was calculated to be:
(11,5 − 2,5) ÷ 15,5 = 0,58 mm per day.
Factors that may influence the accuracy of this imate include the following:

) variation in the temperature environment of the larvae,
) larval dispersion and drift,
) a possible peak in spawning shortly after the November cruise.

The temperature did not vary much from vember to December (Figs. 1a and 1b) and th temperature distributions were fairly typical the area between Cape Cross and Cape Frio in rly summer.
Larval drift, as mentioned earlier, is considered have been minimal.
It is unlikely that spawning peaked only after November 1978 cruise, because Le Clus and omas (1981) sampled more pilchard eggs (if exceptional stations, one in December 1978 one in February 1979 are excluded) and made e positive hauls during November than during other month of the 1978/79 survey. The growth mate given here is substantially higher than t of O'Toole (1977), and an undetected peak in awning after the November cruise would have de it still higher.
O'Toole's (1977) calculation of initial growth 19°C water) was as follows:
(11,25 − 3,25) ÷ 24 = 0,33 mm per day.
is calculation is open to the criticism that tching eggs found simultaneously with larvae 25 mm long may have caused a real peak in val abundance later. O'Toole's (*op. cit.*) smallest ngth class was 3,25 mm; smaller larvae probably passed through the meshes of the sampling net used. The smallest mesh net used in this study had a mesh size of 0,300 mm in comparison with the mesh sizes of 0,940 and 0,500 mm used in the earlier survey. A later peak would have caused O'Toole (*op. cit.*) to underestimate the growth rate.

During the 1978/79 survey, a break in spawning after the November spawning is evident. This break would have caused the well-defined nature of the mode in the December larval length-frequency distribution centred at 11,5 mm. A total of 68 per cent of the larvae within this mode were between 10 and 13 mm long (Table II), an indication that little larval dispersion took place.

The larval length-frequency distributions in Table II are shown on Figure 2, along with the calculated initial growth curve deduced in the present study and in that of O'Toole (1977).

The growth rate of the larval cohort, if it is traced into January 1979, is also shown on Figure 2. The chief objections to this speculation would be the large area of larval occurrence in January 1979 (Fig. 1c), the fact that the cruise was carried out from north to south (opposite direction to that of the previous months), and the probability of net avoidance by larger larvae. With these limitations in mind, the growth rate of larvae 11,5-23,5 mm long in 15°C water may tentatively be calculated as:

(23,5 − 11,5) ÷ 41 = 0,29 mm per day.

This result is, however, in fair agreement with that obtained by O'Toole (1977) for larvae in 14-15°C water:

(19,25 − 13,25) ÷ 30 = 0,20 mm per day.

Both sets of results are shown on Figure 2.

CONCLUDING REMARKS

An estimate of the growth rate of pilchard larvae for a period of half a month after spawning (0,6 mm per day) is presented. This estimate is valid for water of about 15°C, a temperature typical of that at a depth of 20 m in the area between Cape Cross and Cape Frio during the summer/autumn spawning season. It was in this area and during this season that 75 per cent of all pilchard larvae caught during the entire 1978/79 survey were taken.

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981

POPULATION DYNAMICS OF ROCK LOBSTER *JASUS TRISTANI* AT THE TRISTAN DA CUNHA GROUP OF ISLANDS

D.E. POLLOCK

The four islands of the Tristan da Cunha group in the South Atlantic yield an annual catch of some 500-800 tons of rock lobster *Jasus tristani*. Catch rates have declined appreciably and mean sizes of individuals in the catches from each island have diminished. Results from tagging during 1977 indicated that male rock lobsters grow much more rapidly than females, mean annual increments of males ranging from 4,5 to 6,4 mm carapace length, compared with those for females of 2 mm or less. Male growth rates and mean sizes of individuals caught differ amongst the islands, and the two parameters appear to be related. Fishing mortality rates determined from tagging suggest that the populations at two of the islands (Nightingale and Inaccessible) are maximally exploited, with sustainable yields of approximately 80 and 175 tons respectivelv Based on yield-per-recruit analyses, and assuming instantaneous natural mortality rates between 0,1 and 0,2, a minimum size limit of 65-70 mm carapace length is recommended for all four islands. The density of rock lobsters and levels of sustainable yield appear to be appreciably lower than in the closely related *Jasus lalandii* stock on the South African west coast. This may result from poor recruitment coupled with a lower carrying capacity of the benthic environment at the oceanic group of islands.

Die vier eilande van die Tristan da Cunha-groep in die Suid-Atlantiese Oseaan lewer 'n jaarlikse vangs van sowat 500 tot 800 ton kreef *Jasus tristani*. Vangkoerse het aanmerklik gedaal en gemiddelde kreefgrootte van die vangste by elke eiland is nou kleiner. Die resultate van die merking gedurende 1977 het aangedui dat mannetjiekrewe baie vinniger groei as wyfies. Gemiddelde jaarlikse doplengtetoename by mannetjies het gewissel van 4,5 tot 6,4 mm, vergeleke met 2 mm of minder by wyfies. Gemiddelde groottes van die krewe en die groeikoerse van mannetjies wissel van eiland tot eiland en die twee parameters hou blykbaar grootliks verband. Mortaliteitskoerse wat volgens merking bepaal is, dui daarop dat die stapels by twee van die eilande (Nightingale en Inaccessible) maksimaal ontgin is, met volhoubare opbrengste van 80 en 175 ton onderskeidelik. Op grond van ontledings van opbrengs per rekruut en 'n veronderstelde oombliklike natuurlike mortaliteitskoers van tussen 0,1 en 0,2 word 'n minimum doplengtemaat van 65 tot 70 mm vir al vier eilande aanbeveel. Die stapeldigtheid en vlakke van volhoubare opbrengs is blykbaar heelwat laer as by die nou verwante stapel van *Jasus lalandii* aan die Suid-Afrikaanse weskus. Dit kan veroorsaak word deur swak rekrutering gepaard met 'n laer dravermoë van die bentiese omgewing by hierdie groep oseaniese eilande.

The rock lobster *Jasus tristani* Holthuis is one of the seven species of the genus *Jasus*, all of which are confined to the southern hemisphere. Holthuis and Sivertsen (1967), in a revision of the *Jasus* species, divided the genus into two clearly differentiated groups:— the "verreauxi" group consisting of one species only, *Jasus verreauxi* (H. Milne Edwards) in New Zealand, and the "lalandii" group, consisting of six species, native to South Africa *(J. lalandii)*, Australia *(J. novaehollandiae)*, New Zealand *(J. edwardsii)*, the Tristan da Cunha area *(J. tristani)*, the Juan Fernandez islands in the S. E. Pacific *(J. frontalis)* and St Paul and Amsterdam islands in the south central Indian Ocean *(J. paulensis)*. The authors placed the latter three species within a "frontalis" subgroup, the remaining three comprising a "lalandii" subgroup. These subgroups were differentiated by the shape and size of carapace spines and by the degree of sculpturation on the abdominal segments. Morphologically, the six species are extremely similar.

Jasus tristani occurs at the islands of Tristan da Cunha, Inaccessible, Nightingale and Gough, as well as at Vema seamount, some 1 680 km east-north-east of Tristan da Cunha (Fig. 1). Heydorn (1969a) described some marked changes in size composition and sex ratios in catches of *J. tristani* made at Vema seamount between 1964 and 1966. He also recorded some underwater observations made at Vema, Gough Island and Tristan da Cunha at this time.

Roscoe (1979) described the fishery for, and biology of, *J. tristani* at the Tristan group of islands, based on studies at Tristan between 1971 and 1973. He also recorded the historical performance of the fishery from the time of its inception in 1949, until 1976. The rock-lobster stocks are fished by one company which has sole rights over exploitation of the marine resources of the islands. No minimum size limit is as yet in force, and the total annual yield is about 500—800 tons. Pollock and Roscoe (1977) have described growth rates of rock lobsters at two of the islands, from the results of a tagging programme conducted in 1971—1973.

This report describes the progress of the fishery subsequent to 1976 and presents an analysis of a

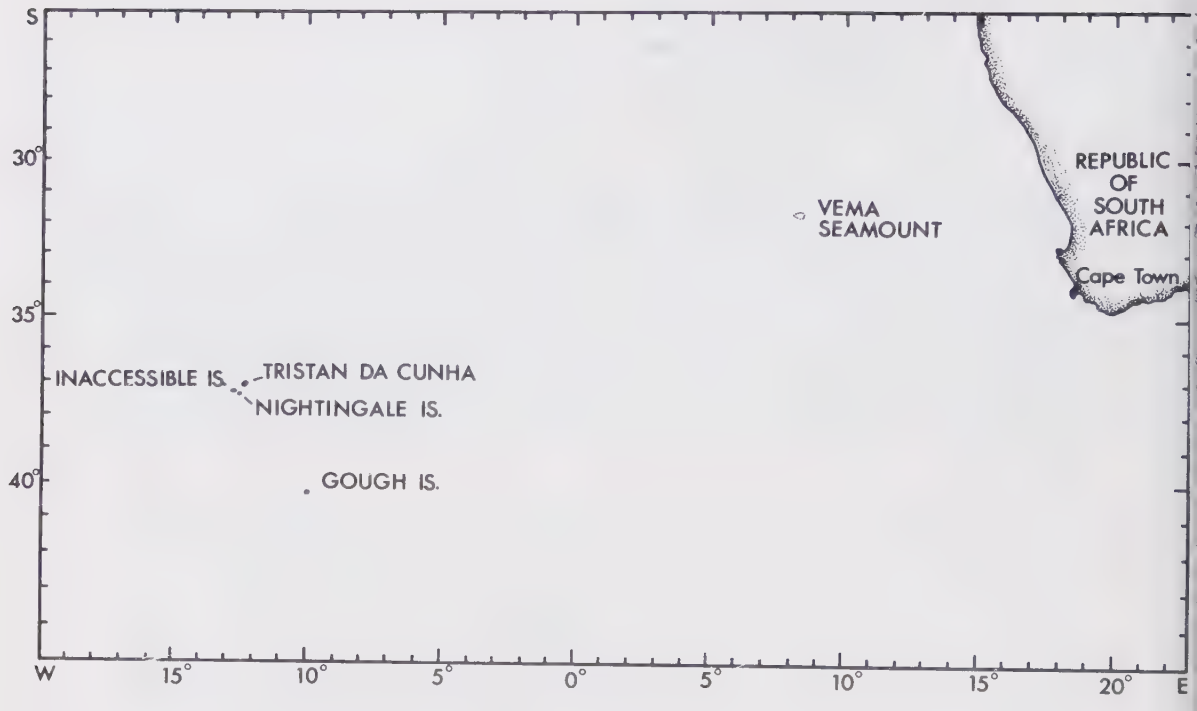


Fig. 1: Location of the Tristan da Cunha group of islands

second, more intensive tagging programme conducted at all four islands during 1977. Some inter-island variations in growth rates are described, and their effects on yields and minimum size limits are evaluated. The productivity of *J. tristani* stocks is compared with that of *J. lalandii* off the west coast of South Africa, and is discussed in relation to rock-lobster recruitment and to the carrying capacity of the two widely differing insular and coastal environments.

METHODS

Detailed records of catch and fishing effort were available from the company responsible for exploitation and management of the rock-lobster fishery at the island group, which is itself part of the British Dependency of St Helena. Data for each island were recorded and analysed separately, special distinction being made between Tristan da Cunha and the other three islands, because fishing methods, vessels and gear differ radically at Tristan da Cunha. At Tristan, virtually all fishing takes place from small boats manned by the islanders, whereas at the other uninhabited islands exploitation takes place from two or three large catcher vessels based in Cape Town.

Size composition of catches was available from a number of sources, including the distribution of size categories of tails packed, sampling of landed catches at Tristan, and sampling of catches on board the catcher vessels while at sea.

Between September and November 1977, some 15 000 rock lobsters caught during commercial fishing operations were tagged and released at sea. Numbers released at Tristan da Cunha were small (600), but over 14 000 animals were distributed over the fishing grounds at the remaining three islands. The tag used was an FT-2 dart tag supplied by Floy Manufacturing Co. and inserted dorsally between the second and third abdominal segments. Tag loss at moulting is known to be substantial, varying from 28 to 50 per cent for *J. lalandii* in South African waters (Newman 1973, Pollock 1978), so that the number of recaptures which had moulted once after tagging had to be adjusted for tag loss. A successful reward system was initiated to ensure that all tag recaptures

re reported.
In order to facilitate analysis, the fishing grounds ound each island were divided into square-mile ds identified with an alpha-numeric code. captured tagged animals were frozen on board e catcher vessels (or at the factory on Tristan da nha), labelled with date, position of recapture id number), vessel and depth. When the catch s brought to Cape Town, each recaptured imal was measured, sexed and the state of shell ted. Animals which had moulted could be tinguished by a raised lip or a scar on the cond abdominal segment at the point of insertion the tag.
Only tags recovered during the first fishing season ter tagging (December 1977—April 1978) were ed for stock assessment purposes. Tag returns ring the second season after tagging (September 78—April 1979) were not considered to be liable for estimating rates of fishing mortality cause the number of returns was very low, obably because of tag loss or individual mortality ter one or more moults in the intervening riod.

FISHERY PERFORMANCE

shing effort

A detailed description of fishing effort in the riod 1949—1976 has been given by Roscoe 979), and changes during this period will not be alt with in detail here.
The local fleet at Tristan da Cunha is at present ade up of some 20 small boats, including dinghies d inboard-motor-powered boats of different sizes. ese operate throughout the year whenever eather conditions allow, inclement weather nerally limiting fishing to about 70 days per ear (Roscoe 1979). Gear consists of hoopnets nd light traps set on individual buoyed lines and auled by small winches.
From 1974 to 1978, three large catcher vessels ased at Cape Town fished at Inaccessible, ightingale and Gough Islands. One vessel was ithdrawn in 1978. All these vessels operated by etting and hauling daily 6—9 longlines of 20 traps ach. Effort for these vessels is subsequently xpressed as the number of trap-hauls. Traps used re large, metal-framed, rectangular in shape and overed with polyethylene netting. These side-ntry traps were introduced in 1974 to replace a ess efficient, plastic kavel top-entry trap.

Fishing by the large catcher vessels commences in spring (August/September) and usually continues through the summer and autumn months until about May each year.

Catch per unit effort

Roscoe (1979) has described well-defined within-season trends in catch per unit effort (C.P.U.E.) at all the islands. These trends he ascribed to moulting and reproductive cycles, as well as to the impact of fishing on stocks. C.P.U.E. values normally reach a peak between October and December each year, shortly after the male moulting period, and decline after that.
In this report, gross trends in C.P.U.E. are compared over a long time-scale. Use is therefore made of Roscoe's (1979) earlier data as well as of information acquired subsequent to 1976. Comparison of average C.P.U.E. (by weight) between islands may give an indication of differences in stock density or biomass as well as provide an index of trends in stock abundance at the islands.
Trends in catch, effort and C.P.U.E. are described separately for Tristan da Cunha, because the difference in methods of exploitation between this and the remaining three islands renders direct comparison impossible.

Tristan da Cunha

Fishing effort is measured in boat-days, because the three different classes of small boats (dinghies, 5,6-m motorboats and large powerboats) operate with different numbers of hoopnets and traps. From 1971, the effort was standardized by weighting each boat-type by its fishing power relative to that of a large powerboat. The total seasonal fishing effort could then be expressed as the number of large-powerboat-days.
Table I lists total catches, total effort and adjusted C.P.U.E. for the seasons 1970/71 to 1978/79. Data were not obtainable for October, November or December 1977 and, because catch rates are normally highest in these months, the mean C.P.U.E. for 1977/78 is considered to be biased on the low side.
In general, no clear trends are apparent in fishing effort which, as explained earlier, is largely a function of prevailing weather conditions during each season. C.P.U.E. has also fluctuated considerably, but a downward trend is apparent

Table I: Catch, effort and C.P.U.E. of small boats at Tristan da Cunha, 1970/71—1978/79 (first six seasons' data from Roscoe 1979)

Season	Catch (kg whole weight)	Total effort (large-powerboat-days)	C.P.U.E. (kg/large-powerboat-day)	Total catch** (metric tons whole weight)
1970/71	211 900	no data	no data	230
1971/72	231 900	454	511	281
1972/73	206 500	497	415	242
1973/74	169 760	552	308	180
1974/75	165 845	479	346	200
1975/76	178 300	482	370	212
1976/77	148 512	370	401	180
1977/78	69 091*	336*	206	112
1978/79	156 580	549	285	168

* incomplete totals (October, November and December 1977 omitted)

** catch information supplied is consistently less than the true total catch

which may be indicative of declining stock abundance at this island.

Inaccessible, Nightingale and Gough Islands

Catches made at these three islands have supplied between 60 and 76 per cent of the total catch from all four islands over the past nin seasons. Each season's total catch, total effort an calculated mean C.P.U.E. for each island durin the period 1970/71—1978/79, are given in Tab II.

C.P.U.E. data, when used over an extende time-scale, can give some indication of trends i stock density with time. However, fishing at eac island may take place in differing months of th various seasons, and seasonal means may nc therefore always be representative. Another factc of importance is the effect of changes in gear. I 1974, the three catcher vessels were equippe with larger metal-framed traps, replacing the plasti kavel traps. At the same time, catch and effo statistics were collected more rigorously as a resu of the introduction of newly designed fishing log More adequate reporting plus the use of the new more efficient traps resulted in an apparently larg increase in C.P.U.E. at all three islands after th 1973/74 season (Fig. 2).

Catch rates virtually doubled between th 1973/74 and the 1974/75 seasons. Pollock an Augustyn (in preparation) have shown that, in th fishery for the spiny lobster *Palinurus gilchristi* o the South African south coast, the rectangula trap is approximately 1,8 times more efficient tha the kavel trap. The apparent doubling of catch rates at the three islands may therefore be th result solely of the change in gear. In any event, i is not considered likely that the rise in C.P.U.E after 1973/74 was indicative of an increase ir stock abundance. The trend since 1974/75 ha

Table II: Catch, effort and C.P.U.E. at Inaccessible, Nightingale and Gough Islands, 1970--1979

Season	Nightingale			Inaccessible			Gough			All 3 islands	
	Catch*	Effort†	C.P.U.E.‡	Catch*	Effort†	C.P.U.E.‡	Catch*	Effort†	C.P.U.E.‡	Catch*	Effort†
1970/71	141	24,3	5,8	80	19,8	4,1	123	15,4	8,0	344	59,5
1971/72	98	23,7	4,1	147	38,3	3,8	380	69,9	5,7	625	128,8
1972/73	49	13,2	3,7	116	43,9	2,6	190	43,4	4,4	355	100,5
1973/74	77	12,5	6,1	214	32,6	6,6	161	29,5	5,5	452	74,6
1974/75	166	13,1	12,7	282	28,1	10,0	182	10,2	17,8	630	51,4
1975/76	245	28,7	8,5	133	14,0	9,4	283	20,6	13,8	661	63,3
1976/77	182	22,4	8,1	224	23,7	9,5	64	12,4	5,2	470	58,5
1977/78	71	11,0	6,4	138	31,0	4,5	130	16,4	7,9	339	58,4
1978/79	34	5,9	5,6	123	23,6	5,2	110	14,3	7,7	267	43,9

*Catch: metric tons whole weight
†Effort: thousands of traps hauled
‡C.P.U.E.: kg whole weight per trap hauled

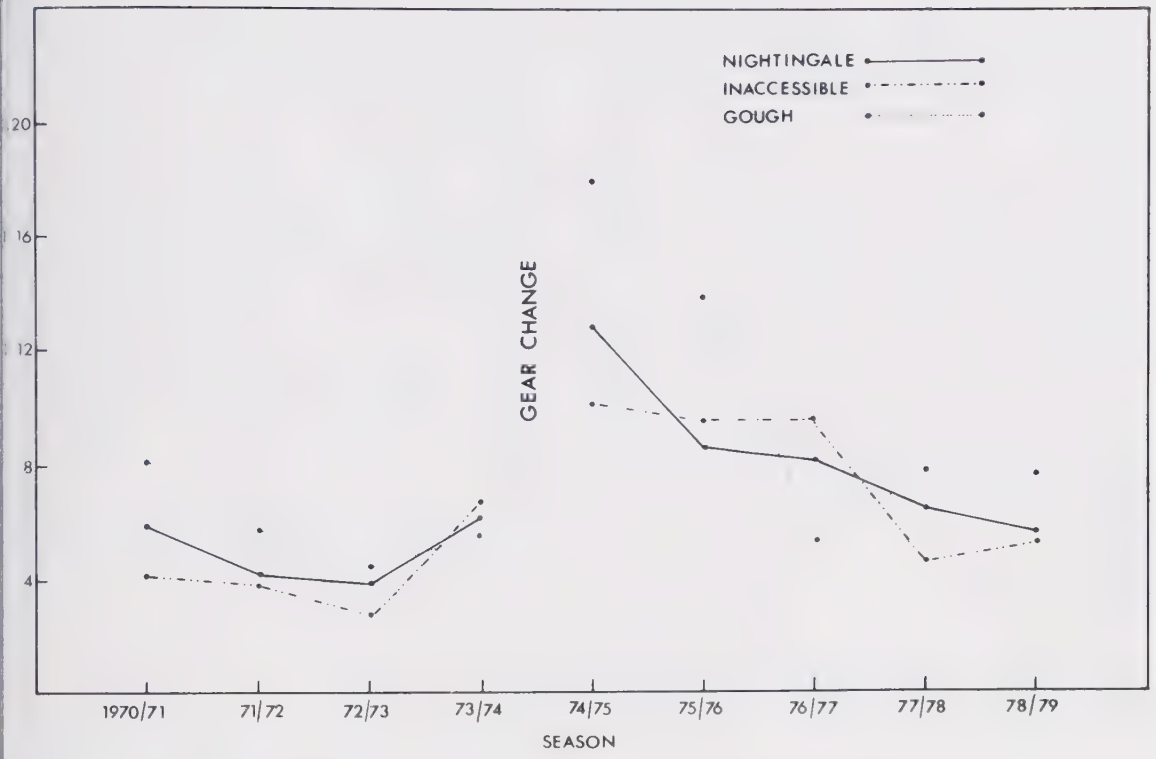


Fig. 2: Catch per unit effort for longline trap fishing, 1970/71-1978/79

n downwards, suggesting that stocks at all three nds have been declining.

omparison of catch rates between islands is resting, despite shortcomings in the data. Prior 973/74, C.P.U.E. levels were highest at Gough nd, slightly lower at Nightingale and lowest at cessible. Since the 1974/75 season, the C.P.U.E. ough has remained highest, with the exception e 1976/77 season, while that at the other two nds was usually lower. In 1975/76 and 1976/77, catch rate at Inaccessible exceeded that at htingale, whereas in the other seasons the erse was the case. Assuming that there are no erences in the catchability of rock lobsters by ted traps at the three islands, the higher C.P.U.E. gests that stock density at Gough is greater n at the other two islands.

SIZE COMPOSITION

Two sources of information are available: direct mpling and pack categories.

Sampling of catches

Size frequency distributions from samples measured on the island or on board the catcher vessels are shown for each island and season separately in Figures 3—7. These distributions allow gross comparisons to be made of changes in size composition between two sampling periods five years apart, i.e. 1971/72—1972/73 and 1976/77—1977/78. Sample sizes at Nightingale and Gough (north) in 1976/77 were small and the data have been omitted as unreliable.

Tristan da Cunha — The large difference in size composition between the historical situation in 1949/50 and that of 1971/72—1972/73 has been commented on by Roscoe (1979). By 1976/77—1977/78, a further decline was apparent (Fig. 3), a fact best evidenced by the increased proportion of animals smaller than 65 mm (carapace length) in the catches.

Inaccessible — A comparatively large decrease in

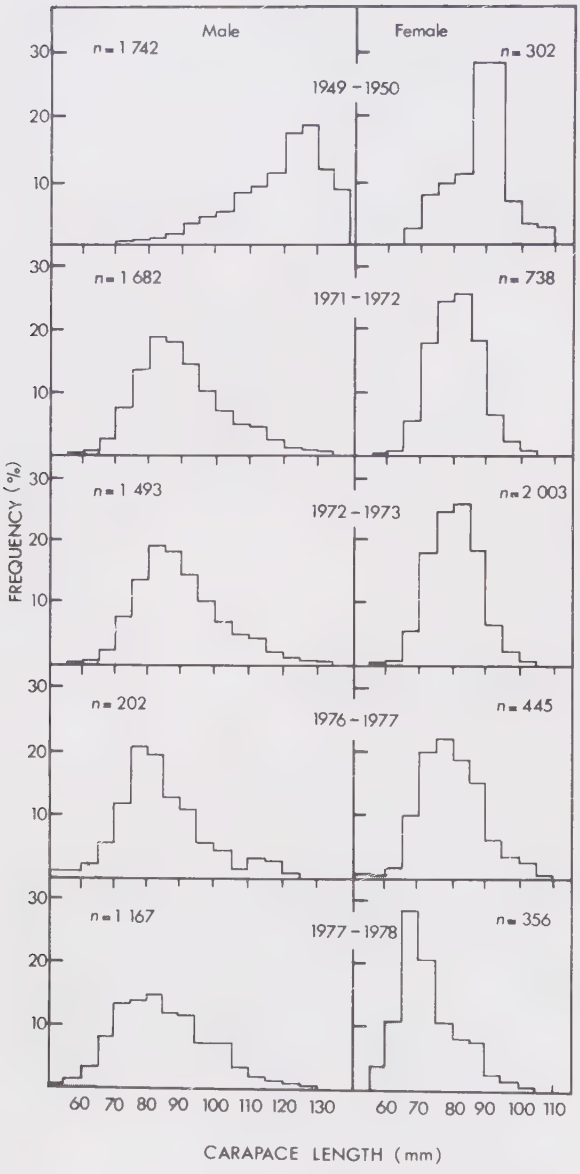


Fig. 3: Size composition at Tristan da Cunha

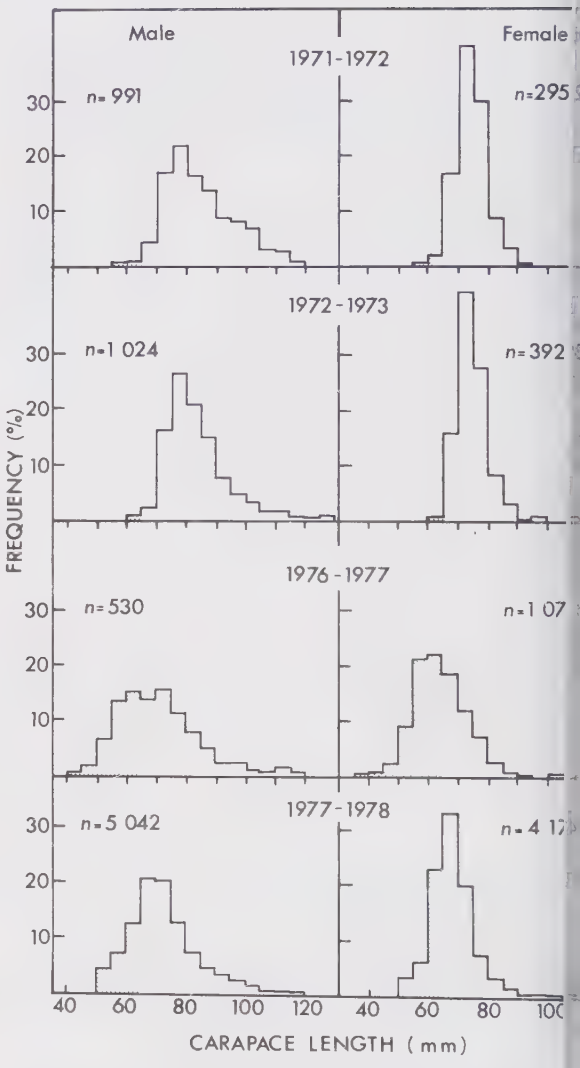


Fig. 4: Size composition at Inaccessible Island

animal size between the two sampling periods of 1971/72—1972/73 and 1976/77—1977/78 is evident (Fig. 4). The increased proportion of individuals of both sexes smaller than 65 mm is noteworthy.

Nightingale — Figure 5 reflects a downward sh in the modal sizes of males and females, as well an increase in the proportion of small anima caught.

Gough Island (north) — Modal sizes are difficu to discern clearly in the case of males (Fig. 6), a changes in size composition are not well define Female size composition appears to have remain relatively stable.

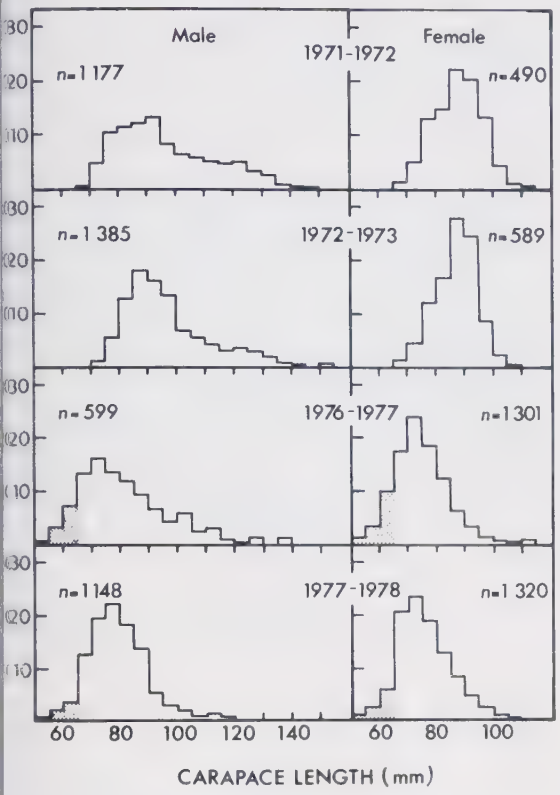


Fig. 5: Size composition at Nightingale Island

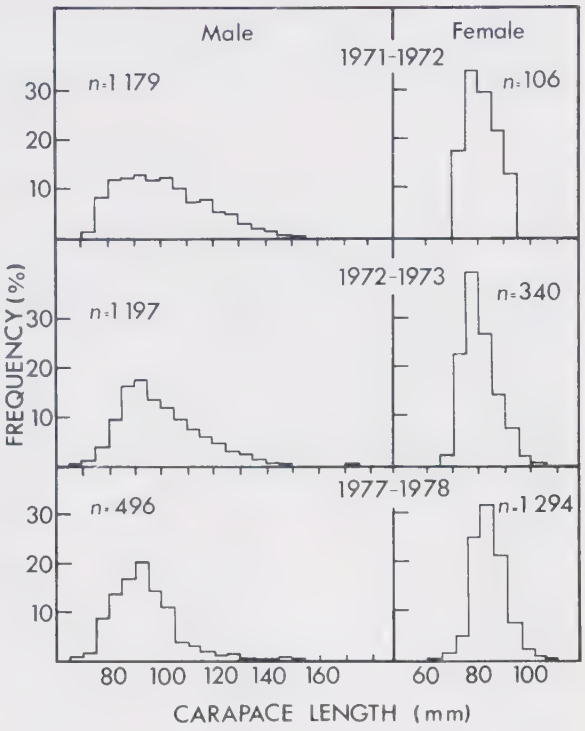


Fig. 6: Size composition at Gough Island (north)

ugh Island (south-west) — Modal sizes are also ficult to define clearly (Fig. 7), probably because mpling intensity varied greatly in the four sons.

neral — The histograms demonstrate that the est individuals are caught at Gough Island the smallest at Inaccessible. The trend at all nds (excepting Gough) has been a clear decline modal sizes and an increase in the proportion small animals in the catch.

nalysis of pack categories

An analysis of categories of tails packed for port provided a second source of information size composition. Export packs comprise only ls heavier than 57 g (2 ounces). Tails smaller an this, originating from rock lobsters with carapace length less than approximately 65 mm, are packed for the South African market in caterpacks together with an indeterminate number of damaged and sub-standard tails from larger animals. These packs were therefore not included in the analysis.

Table III lists mean sizes calculated from pack category distributions and the percentage of M and K categories (the smallest sizes of tails packed) for each island from 1974/75 to 1978/79. No significant, consistent decreases in mean sizes of tails packed are evident from the data. As discussed by Roscoe (1979), analysis of pack categories for size composition has certain drawbacks, and is probably not as sensitive to actual changes in size composition as the method of sampling catches discussed above.

Inter-island variations are clearly reflected by the data. Gough Island consistently produced the largest mean size and the lowest percentage of M and K categories packed. Tristan and Nightingale were similar, particularly in the last two years,

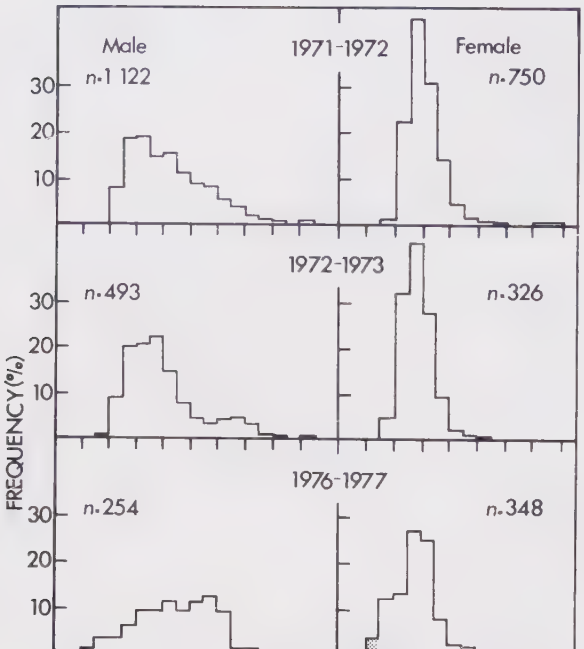


Fig. 7: Size composition at Gough Island (south-west)

whereas Inaccessible provided the smallest mea size and the highest percentage of M and K.

Comparison of trends in size composition

A comparison of data from analysis of si composition and pack categories is made in Tab IV for the 1977/78 season, when adequate da were available from both sources. Both sets data show similar trends, mean sizes being greate at Gough Island, and smallest at Inaccessibl Mean sizes and the percentage of small siz packed or caught were fairly similar at Tristan c Cunha and Nightingale Island.

At each island, the mean sizes from catc sampling were consistently lower than thos calculated from pack category analysis. This partly because sizes smaller than ± 65 mm (i. tails <57 g) were excluded from the pack-catego analysis.

TAGGING AND STOCK ASSESSMENT

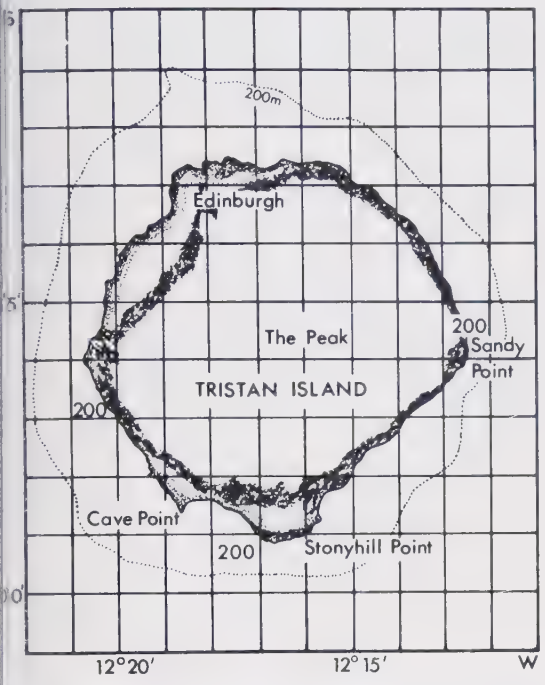
Tristan da Cunha

Six hundred rock lobsters were tagged ar released at three localities in November 1977 c the west, south and east sides of the island (Fig. 8 During the remainder of the fishing season r tagged animals were recaptured, presumab because these localities were only lightly fished, at all. Between September 1978 and March 19 (the following season), a total of 96 tagged anima

Table III: Size composition based on analysis of pack categories

Season	Tristan da Cunha		Inaccessible		Nightingale		Gough	
	Mean size (mm)	M+K(%)	Mean size (mm)	M+K(%)	Mean size (mm)	M+K(%)	Mean size (mm)	M+K(%)
1974/75	84	44	76	88	76	52	*94	*17
1975/76	81	58	79	66	83	49	89	30
1976/77	80	56	76	74	77	51	84	41
1977/78	82	48	75	77	82	47	87	33
1978/79	82	51	76	71	82	47	87	28
Average over five seasons	82	51	76	75	80	49	87	33

* Small sample — excluded from calculation of mean



Tristan da Cunha, showing number of rock lobsters tagged per square-mile block

recaptured by the two large vessels and the islanders' fleet of small boats. By this stage, d animals had dispersed more widely, but could not be considered to have become omly distributed over the whole of the fishing nds. Roscoe (1979) also indicated that ation of tagged animals was limited, most recaptured within one or two kilometres of release points.

rowth information was available from these ptured animals, but no attempt was made to use the returns for stock size estimation because of the non-random distribution of tagged animals within the fishing ground as a whole.

Inaccessible Island

The fishing ground at Inaccessible extends almost to the 200-m isobath (Fig. 9). Over 6 300 tagged rock lobsters were released, mostly close to the island when the fishing vessel was on overnight anchorage, during September and November 1977. Recoveries after November 1977 indicated that dispersal was insufficient to allow random mixing of tagged rock lobsters with the rest of the population. The fishing ground on the west of the island extends as a submerged wave-cut platform for approximately 7 nautical miles seawards. A total of 73 per cent of the tagged lobsters recovered by March 1978 had been recaptured within 2 miles of their release points (Table V), demonstrating the lack of random mixing within the population. An analysis of fishing effort (location of longlines set) during that season showed that approximately 37 per cent of the fishing effort was expended on the western bank where few tagged rock lobsters would have been available to capture. As an approximation, it was assumed that the tag-recapture rate would only have been directly proportional to fishing effort within a distance of ± 2 miles around the island.

The percentage of tags returned per size class is shown in Table VI. Female returns were noticeably lower than those of males in each size class. From size frequency distributions of the catch, it was estimated that 68 per cent of males caught and more than 80 per cent of females were between 60 and 79 mm carapace length. Rates of tag return for these size classes in the catch were 15 per cent for males and 4—5 per cent for females, but they relate to only 63 per cent of the total fishing effort

Table IV: Mean sizes and percentage of smallest sizes packed/caught in the 1977/78 season

Island	Pack category analysis		Size composition sampled from catch	
	Mean size (mm)	M+K(%)	Mean size (mm)	<65 mm (%)
stan da Cunha	82	48	81	11
ccessible	75	77	71	20
htingale	82	47	77	7
ugh	87	33	85	0,1

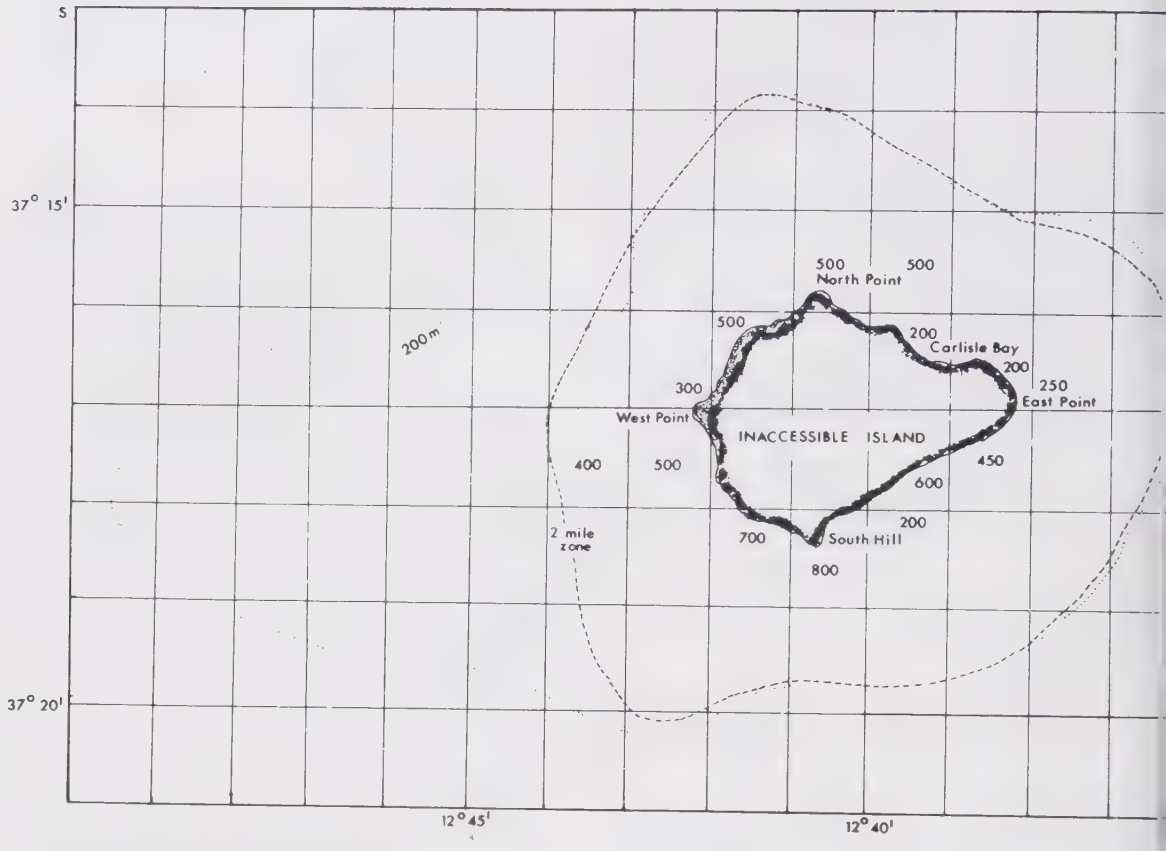


Fig. 9: Fishing ground at Inaccessible Island, showing number of rock lobsters tagged per square-mile block

at Inaccessible in 1977/78 (i.e. the fishing that took place inside the 2-mile zone — Fig. 9).

In order to calculate the population size over the whole of the fishing ground, it is necessary to assume that the rate of fishing mortality within and outside the two-mile zone was the same, i.e. that the overall tag return rate would have remained at 15 per cent for males and 4—5 per cent for females even if tagged animals had been dispersed throughout the whole of the fishing ground. The accuracy of the ensuing calculation rests heavily on this assumption.

Stock sizes were estimated using the equation of Bailey (1951):

$$N = \frac{T\ (C + 1)}{R + 1}$$

where N = population size in numbers
T = numbers tagged
C = catch in numbers
R = number of tags returned.

Population sizes were estimated at approximat 1,5 million males and 4,5 million females in t catchable size range (50—130 mm in carapa length). The population sex ratio thus calculat is 25 per cent males : 75 per cent females.

Nightingale Island

The fishing area at Nightingale is the smallest all four islands. The 200-m isobath, approximat demarcating the outer limit of the area, is mos

e V: Number and percentage of tag recoveries by distance moved from release point at Inaccessible — data for three fishing vessels combined (each block is one square nautical mile in area)

nber of blocks moved	Animals recaptured	
	Frequency	Percentage
0*	33	10
1	191	57
2	21	6
3	21	6
4	20	6
5	22	6
6	15	4
7	8	2
8	3	0,9
9	1	0,3
10	2	0,6
11	1	0,3

= release block

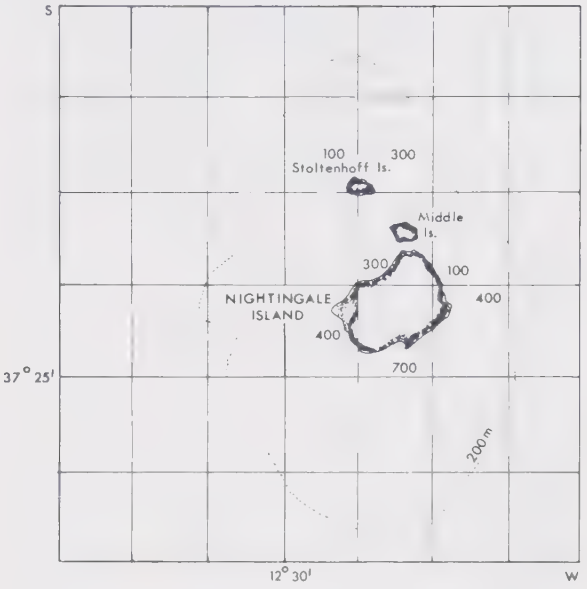


Fig. 10: Fishing ground at Nightingale, showing number of rock lobsters tagged per square-mile block

hin one or two miles of the shoreline (Fig. 10). ring September and November 1977, 2 384 ged rock lobsters were released all around the nd. Dispersal of these animals within the rest he population was assumed to be more plete than at the other islands, owing to the ed extent of the ground.

nalysis of tag returns by size class and sex is wn in Table VII. Again tag-return rates of females were much lower than those of males of the same sizes, an exception being in the 90—99 mm size class. This discrepancy probably resulted from the relatively small numbers tagged in this size class.

Analysis of size composition data showed that three size classes, i.e. 60—69 mm, 70—79 mm and 80—89 mm, together comprised 88 per cent of all males and 89 per cent of all females caught. The

VI: Record of tagging and recoveries of male and female rock lobsters per size class at Inaccessible Island, 1977/78

class m)	Males		Females	
	Number tagged	Recoveries (%)	Number tagged	Recoveries (%)
-69	1 221	13	1 879	4
-79	1 416	17	889	5
-89	490	17	135	10
-99	232	17	12	0
-109	62	23	0	—

Table VII: Record of tagging and recoveries of male and female rock lobsters per size class at Nightingale Island, 1977/78

Size class (mm)	Males		Females	
	Number tagged	Recoveries (%)	Number tagged	Recoveries (%)
60—69	176	19	324	5
70—79	477	27	561	9
80—89	348	20	290	11
90—99	87	8	97	12
100—109	22	0	14	0

Table VIII: Record of tagging and recoveries of male and female rock lobsters per size class at Gough Island, 1977/78

Size class (mm)	Males		Females	
	Number tagged	Recoveries (%)	Number tagged	Recoveries (%)
60–69	10	0	37	0
70–79	145	0	1 299	1
80–89	489	1	2 231	1
90–99	464	3	397	1
100–109	208	8	14	0

rates of tag return for these classes combined were 23 per cent for males and 8 per cent for females.

Stock sizes were estimated for the different size classes and for each sex separately. Males in the catchable size range (50–130 mm) were estimated at approximately 440 000, and females (50–110 mm) at approximately 895 000. The calculated sex ratio in the population is therefore 33 per cent males : 67 per cent females.

Gough Island

In contrast to the other islands, little fishing takes place at Gough deeper than approximately 90 m. In addition, virtually no fishing appears have been done on the sheltered eastern side the island for several years. Apparently catch on the eastern side have declined severe probably because of overfishing in the past.

Over 5 000 animals were tagged during Octob and November 1977 and released in the are where fishing took place in the 1977/78 seas (north, south and west). Analysis of the tag retur by size class and sex are shown in Table VI Rates of return were extremely low for all siz and, as at the other islands, fewer females th males were recaptured.

The overall tag return rate during 1977/78 w only 3,7 per cent for males and 1,1 per cent f females. No population estimates were ma because of these low rates of return.

GROWTH

Table IX lists mean carapace-length increme for tagged animals of both sexes which had moult once before recapture. The data are arranged size class as well as by island and by sex. T observations are considered noteworthy: first growth increments of females are much smal than those of males of equivalent size; secondly would appear that male increments are larger Gough and Nightingale than at the remaining t islands.

Table IX: Mean growth increments of once-moulted male and female rock lobsters at the four islands (sample sizes in brackets)

Island	Sex	Mean increment (mm) per size class					
		60–69 (mm)	70–79 (mm)	80–89 (mm)	90–99 (mm)	100–109 (mm)	All size classes combined
Tristan	males	5,5(10)	5,1(20)	4,4(16)	5,3(5)	—	5,1(51)
	females	2,7(9)	1,3(7)	0,6(7)	0,5(2)	—	1,5(25)
Inaccessible	males	4,8(47)	4,5(60)	4,1(15)	3,4(5)	4,0(3)	4,5(130)
	females	2,0(21)	1,8(6)	2,0(1)	2,0(1)	—	1,0(29)
Nightingale	males	6,9(16)	6,2(28)	6,7(28)	6,0(2)	3,0(2)	6,4(108)
	females	2,7(29)	2,0(60)	1,2(28)	1,1(8)	0,0(1)	1,9(126)
Gough	males	—	7,3(2)	5,8(3)	6,9(4)	5,7(5)	6,4(14)
	females	—	2,0(4)	1,9(15)	—	–	1,9(19)

Table X: Results of regression of mean increment against carapace length at tagging for males

Island	Mean increment (mm)	Standard deviation (mm)	N	r	P
Tristan da Cunha	5,1	1,7	51	−0,28	0,01<P<0,05
Inaccessible	4,5	1,3	130	−0,1	<0,05
Nightingale	6,4	2,5	108	−0,1	<0,05
Gough	6,3	1,6	14	−0,22	<0,05

Table XI: Results of regression of mean increment against carapace length at tagging for females

Island	Mean increment (mm)	Standard deviation (mm)	N	r	P
Tristan da Cunha	1,5	1,2	25	−0,7	<0,01
Inaccessible	2,0	1,4	29	−0,1	>0,05
Nightingale	1,9	1,4	126	−0,22	<0,05
Gough	2,0	0,8	19	−0,14	>0,05

For detailed comparisons, the sexes are treated parately.

owth of males

Linear regression analysis of increment against rapace length at tagging showed that increments d not decline significantly with increasing size, cept possibly at Tristan da Cunha. Mean crements, together with standard deviations, mple sizes *(N)*, regression coefficients *(r)* and nificance values *(P)* are given in Table X.

In order to examine variations in growth rate tween islands, means were tested for significance difference, and it was found that growth at htingale and Gough did not differ significantly > 0,05). Growth at Tristan and Inaccessible fered significantly from each other ($P < 0{,}001$) d from the remaining two islands ($P < 0{,}05$).

owth of females

inear regression analysis of increment against rapace length showed significant relationships Tristan da Cunha and Nightingale Islands, but Gough and Inaccessible the data indicated that crement was independent of carapace length at gging. Regression parameters are shown in Table i.

Mean increments at all four islands were almost mm for all size classes combined. The mean owth at Gough and Inaccessible was identical d growth increments were independent of size. t the other two islands, growth increments creased significantly with size, and linear gressions were tested for significance of fference of slopes and elevations (Snedecor and ochran 1967, p. 432). The test showed no gnificant differences (slopes $F_{1,147} = 0{,}26$, $P > 0{,}05$; elevations $F_{1,148} = 2{,}31$, $P > 0{,}05$).

Growth rates of females did not therefore differ significantly between the four islands. However, increments in general were so small that it is doubtful whether significant differences in growth could be recorded when using carapace length as a standard measure of size.

YIELD-PER-RECRUIT ANALYSIS AND MINIMUM SIZE LIMITS

Typical yield-per-recruit curves are shown in Figure 11 for males and females separately at two likely levels of instantaneous natural mortality *(M)*. Use was made of growth data from Tristan da Cunha, and the model used was that of Thompson and Bell (Ricker 1958). The assumption made in the yield-per-recruit model is that recruitment is complete for both sexes at 60-mm carapace length, and that knife-edge selection takes place at a size of 65 mm.

The generalized yield-per-recruit graph (Fig. 11) shows that, for both sexes, the maximum sustainable yield (i.e. the highest points on the curves) can be maintained at a level of instantaneous fishing mortality *(F)* of approximately 0,3. The shapes of the curves suggest that long-term sustainable yields cannot be increased to any extent by increasing fishing mortality (i.e. fishing effort) to levels greater than about $F = 0{,}3$. This is applicable to both levels of natural mortality chosen. The graphs also indicate that the actual level of sustainable yield (or yield per recruit) is highly sensitive to the rate of natural mortality. Unfortunately, M is not known with certainty, but it has been assumed by other authors to be low for spiny lobsters. For example, values of between 0,1 and 0,2 have been computed or assumed for *Jasus lalandii* (Newman 1973, Pollock 1978) and *Panulirus*

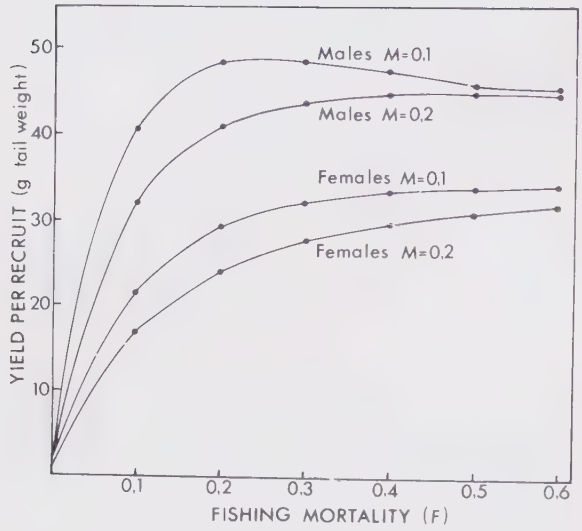


Fig. 11: Yield-per-recruit curves for male and female *Jasus tristani* at two levels of instantaneous natural mortality (*M*)

cygnus (Morgan 1977). Also, the curves show that yields of males are considerably higher than those of females, owing to the faster growth rates of the former.

Because males appear to be more heavily exploited than females at all four islands, and because growth rates of males vary significantly between the islands, an attempt was made to determine optimum minimum size limits for males at each island, using growth data available from the tagging programme. Owing to the much slower growth rates of females, their yield would always be optimized at the lower size limits.

Actual values of yield per recruit (tail weight in gramme per recruit) were computed for each island at minimum sizes ranging from 60 to 91 mm carapace length, for values of M of 0,1 and 0,2. Results were computed for F-values ranging from 0,1 to 0,6 for each island. In order to simplify the data and facilitate comparison, only yield-per-recruit values at $F = 0{,}3$ (i.e. pertaining to the approximate level of maximum sustainable yield) are listed in Table XII for the various minimum size limits. As noted earlier, results are very sensitive to the value of M chosen, and in fact the data indicate that yield per recruit increases with increasing minimum size at each island if M is assumed to be 0,1. In contrast, at the higher level

Table XII: Yield per recruit at fishing mortality $F =$ (for each island, at two different levels of natural mortality (M), and at different minimum size limits

Minimum size limit (mm)	Yield per recruit (g)	
	M=0,1	M=0,2
Tristan da Cunha		
60	54	39
65	57	38
70	60	37
75	62	35
80	64	—
85	65	—
Inaccessible		
60	52	38
65	54	37
70	56	35
75	57	33
84	56	27
Nightingale		
60	62	45
67	67	45
74	72	44
80	75	43
Gough		
60	60	44
66	66	44
73	71	43
79	74	42
91	77	—

of natural mortality, yield per recruit actual decreases (albeit very slightly) with increasir minimum size.

Owing to the sensitivity of yield curves to M, compromise has to be reached if any conclusio are to be drawn with regard to optimum minimu sizes. One method of doing this is to combin results for $M = 0{,}1$ and $M = 0{,}2$ and express th resultant mean yield-per-recruit values as perce tages of the yield at approximately 65 mm carapac length, in order to facilitate comparison. The resul are shown in Table XIII, and it is concluded that

(i) at Tristan da Cunha and Inaccessible Island yield per recruit is not very sensitive to mini mum size limits between 60 and 75 mm i carapace length;

e XIII: Yield per recruit at fishing mortality $F=0.3$, natural mortalities $M=0.1$ and $M=0.2$ combined, expressed as percentage of yield-per-recruit value at 65-mm minimum size limit

Minimum size limit (mm)	Percentage of yield-per-recruit value at 65 mm
Tristan da Cunha	
60	99
65	100
70	101
75	101
Inaccessible	
60	99
65	100
70	99
75	98
85	88
Nightingale	
60	96
67	100
74	103
80	103
Gough	
60	96
66	100
73	103
79	104

(ii) at Gough and Nightingale Islands, because of faster growth rates, yield-per-recruit values increase slightly at minimum size limits larger than ± 65 mm, so that there might be some advantage in establishing a minimum size limit larger than 65 mm at these islands.

For practical reasons, it is not possible to implement different minimum size limits at different islands of the group. In addition, it is necessary to examine the effect of any proposed size limit on the fishery at present, i.e. how much of the present catch would be "lost" by having to return undersized animals to the sea. This is an important economic consideration. Table XIV shows this effect at four different minimum size limits between 60 and 75 mm in carapace length. The data (derived directly from size composition information) shows that, at present, the weight of catch that would be "lost" at a minimum size of 65 mm is low (6 per cent overall), although as much as 18 per cent (by weight) would have to be rejected at Inaccessible Island. For a 75-mm size limit, the corresponding "losses" would be 30 per cent overall, and 62 per cent at Inaccessible.

DISCUSSION

Analysis of available fisheries data over the past nine years has indicated a decrease in both size composition and catch per unit effort at Nightingale, Inaccessible and Gough Islands, although changes in size composition at the latter island have been slight. At Tristan da Cunha sizes

e XIV: Percentage of the catch at each island by weight and by numbers (in parenthesis) that would be discarded if different minimum size limits were enforced — data from 1977/78 size composition information

Minimum size limit (mm)	Percentage that would be discarded				
	Tristan da Cunha	Inaccessible	Nightingale	Gough	All islands combined
60	1 (2)	6 (11)	1 (3)	0 (0,02)	2
65	3 (8)	18 (28)	3 (7)	0,03 (0,1)	6
70	11 (20)	41 (55)	15 (24)	0,4 (1,0)	17
75	23 (36)	65 (76)	31 (45)	4 (7)	30

have declined, but no clear trends in C.P.U.E. have been evident. It is clear that exploitation has been making a considerable impact on the stocks, and the tagging results have confirmed that exploitation rates at two of the islands (Nightingale and Inaccessible) are at levels high enough to attain maximum sustainable yields. These are tonnages of about 80 and 175 tons for Nightingale and Inaccessible Islands respectively, estimates which are considerably lower than the figure given by Roscoe (1979) of 433 tons (130 tons tail weight) for Inaccessible and Nightingale combined. However, these earlier estimates were not based on tagging, and the decline in C.P.U.E. since that time suggests that population sizes may have declined appreciably. The population at Gough Island appears to be only lightly exploited at present, although this observation will have to be confirmed by further tagging.

At Tristan da Cunha, insufficient numbers of rock lobsters were tagged and distributed to allow an assessment of fishing mortality or stock size. However, during an earlier tagging programme conducted in 1971-73 (Roscoe 1979), tag-return rates of 19 per cent for males and 4 per cent for females were obtained, pertaining to a catch of 148 tons. From yield-per-recruit computations, it was calculated that the maximum sustainable yield (at an instantaneous fishing mortality rate of $F = 0{,}3$ for males) would be about 200 tons (whole weight) for the population size which existed then. Catches made between 1971 and 1979 have fluctuated between 112 and 280 tons with a mean of 197 tons. The conclusion which can be drawn is that fishing effort, which is largely limited by weather conditions, has been such that catches have fluctuated around the level of maximum sustainable yield at Tristan da Cunha.

The results of all tagging conducted to date suggest that males are more heavily exploited than females, probably as a result of a difference in catchability between the sexes. Sex-related differences in catchability have also been described by Pollock and Beyers (1979) and Pollock (in press) for *J. lalandii* in South African waters, and they were found to be caused by seasonal changes in feeding behaviour associated with moulting cycles.

Growth rates of males were found to be significantly greater at Gough and Nightingale than at the other islands of the group, whereas growth at Inaccessible Island was lowest. These results are in fair agreement with earlier results given by Pollock and Roscoe (1977) for Tristan da Cunha. Their results indicated that increments of both males and females declined with increasi size of animal, and mean increments ranged fro ± 6 mm to 3 mm for males between 73 and 109 m in carapace length. Female increments we generally less than 2 mm per moult. Prelimina indications were that growth at Tristan and Nighti gale was more rapid than at Inaccessible (Pollo and Roscoe *op. cit.*). These findings have nc been confirmed by the present study, in which far greater number of observations were ava able.

The inter-island variations in growth rate appe to have a marked influence on size compositio because mean sizes in commercial catches we shown to be smallest at Inaccessible and largest Gough Island. However, the mean size Nightingale Island is considerably smaller tha that at Gough (despite identical growth rate and it is likely that differential rates of exploitatic have also had a significant effect on siz composition. Nightingale Island has the smalle fishing ground of the four islands, with an area only 38 km² compared to Tristan da Cunha 71 km² and Inaccessible's 124 km² (Roscoe 1979 and it is likely that fishing intensity has bee greater at Nightingale than elsewhere. This cou have caused a more rapid decrease in the numb of large animals at Nightingale Island since explo tation first began in about 1949.

Variation in growth rates has also complicate the choice of an optimum size limit. Analysis the available data suggests that the best con promise would be to apply a minimum size lim lying between 65 and 70 mm in carapace lengt This limit should curtail the escalating number smaller (non-exportable) fish being caught, as we as optimize yields to a greater extent than is th case at present.

The reasons for the observed differences i growth rates of rock lobsters between the fou islands are not easy to identify. Differences i water temperature alone are not likely to be causative factor, because growth rates at Goug Island are rapid, despite the fact that water tem peratures at Gough are generally about 3°C lowe than at Tristan da Cunha (Roscoe 1979). Wate temperatures at the three northern islands of th group are likely to be similar, because Nightingal and Inaccessible islands are situated only a fe kilometres south of Tristan da Cunha. Yet ever here, growth rates differ significantly between th islands. The variations in growth could possibl be related to differences in the productivity o important rock-lobster food sources on th grounds, but until such time as a detailed environ

ental study can be carried out, the matter is pen to conjecture.

It is both interesting and informative to compare tch rates of *J. tristani* with catch rates of the me type of trap used in the South African fishery r *J. lalandii*. Assuming that there are no fferences in behaviour between the two closely lated species which might affect their relative lnerability to capture by the same type of trap, mparison of catch rates might provide a rough dication of the relative density of stocks, and low some broad conclusions to be drawn garding the productivity of the insular *J. tristani* ck relative to the coastal *J. lalandii*. A minimum e limit of 89 mm has been enforced since 1933 the latter species, and naturally this has had a arked effect on the size composition of the uth African commercial catch.

To allow direct comparison of catch rates of ps in the two fisheries it is necessary to convert ass to numbers of rock lobsters per trap-haul d, in the case of the South African fishery, to se this average by the proportion of undersized imals in the catch which are normally discarded. r the purpose of comparison, two fishing grounds similar size and with similar rock-lobster growth tes were chosen — Nightingale Island, and ssen Island off the Cape west coast. Average tch rates over the past four seasons were culated as approximately 80 rock lobsters per p-haul at Dassen, compared with approximately per trap-haul at Nightingale.

These figures, rough as they might be, suggest t rock-lobster density may be some three times ater at a typical highly productive West Coast und than at an equivalent fishing ground at the stan group. A further example of the large parent difference in productivity between *J. tani* and *J. lalandii* is evident in a comparison estimates of maximum sustainable yields. Again, ssen Island is compared with Nightingale, and e estimates are 800—1 000 tons and 80 tons spectively, showing an order-of-magnitude fference in sustainable yields from two grounds equal size.

Such differences in productivity of rock-lobster cks cannot be related to differences in growth tes, because growth rates on the two grounds osen for comparison were similar. Clearly, cruitment must be very much greater in the astal environment off the West Coast than at e Tristan group of islands. The phyllosoma larvae *Jasus* species are planktonic, spending several onths drifting passively with the ocean currents fore the final, actively swimming puerulus stage returns to settle in shallow waters near the shore. Off the west coast of South Africa, phyllosoma larvae of *J. lalandii* spend some 9—11 months in the plankton, and the late stages are found in waters 100—350 km off shore, beyond the edge of the continental shelf (Lazarus 1967). Puerulus larvae return inshore to a coastline which stretches for some 750 km in a north-south direction. The possible existence of a homing mechanism which might enable puerulus larvae to return towards the coast across the continental shelf should not be discounted, despite the lack of evidence for such a postulate.

Although no larval surveys for *J. tristani* have been conducted in South Atlantic waters, it is likely that phyllosoma larvae of *J. tristani* are swept vast distances away from the islands by the prevailing currents, which generally flow in an east-north-easterly direction. For example, Heydorn (1969a) has suggested that the isolated population of *J. tristani* at Vema seamount (1 680 km east-north-east of Tristan da Cunha) is maintained by settlement of larvae originating from the Tristan area. There is therefore a strong possibility that the bulk of larvae released from the four islands are lost in the South Atlantic, because the puerulus larvae would have a slim chance of returning to four tiny volcanic islands rising abruptly from depths exceeding 2 000 metres. This could explain a relatively low rate of recruitment to the insular populations in comparison with that to the coastal *J. lalandii* population.

A further important feature is the large difference in primary productivity which exists between the insular and coastal regions, a factor which may control the overall carrying capacity of the benthic environment. Primary productivity in the Benguela upwelling system off the west coast of southern Africa is likely to be some 6—20 times greater than in the oceanic waters surrounding the Tristan group of islands (Ryther 1969).

Dense populations of ribbed mussels *Aulacomya ater* are maintained by the phytoplankton-rich waters off the southern African west coast and are the main food source of *J. lalandii*, which is a predator (Heydorn 1969b, Pollock 1979). Most palinurids are carnivorous, and all are readily caught with fish bait. It is somewhat surprising, therefore, that the natural diet of *J. tristani* is apparently predominantly seaweeds (Heydorn 1969a). However, Heydorn's observations were limited to specimens caught by diving at depths shallower than 33 m where, because water clarity

is good, seaweeds dominate the benthos. Because the bulk of *J. tristani* populations occur in depths of 30—200 m (Roscoe 1979), and individuals may extend into depths as great as 500 m (Heydorn 1969a), where seaweeds are unlikely to occur in quantity, an examination of gut contents of rock lobsters caught at greater depths might provide a different picture.

The relatively low primary productivity of the oceanic waters would, in any event, depress the productivity of secondary and tertiary production levels in the benthos, although this may be countered to some extent by seaweed production.

ACKNOWLEDGEMENTS

The author wishes to thank Mr P.C. Goosen for his help in the collection and analysis of the data and Messrs P. Day and G. Norton of Tristan Investments (Pty) Ltd for their assistance and advice. Review of the manuscript by Dr J.H.M. David and Messrs A. Badenhorst and R.M. Smith is gratefully acknowledged.

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THE BREEDING POPULATION OF WHITE PELICANS *PELECANUS ONOCROTALUS* AT BIRD ROCK PLATFORM IN WALVIS BAY, 1949-1978

R. J. M. CRAWFORD, J. COOPER** AND P. A. SHELTON*

White pelicans *Pelecanus onocrotalus* first bred at Bird Rock platform in the late 1940's. Colonization of this platform appears to have resulted from former breeding islands at Sandwich Harbour becoming unsuitable nesting sites through their joining with the mainland and so providing access for mammalian predators. The population at Bird Rock has probably decreased since the late 1960's and early 1970's. Because predation by white pelican chicks on Cape cormorant *Phalacrocorax capensis* eggs and juveniles is known to occur, it is suggested that a large nesting population of Cape cormorants may enhance breeding success of white pelicans.

Wit pelikane *Pelecanus onocratalus* het eers in die laat veertigerjare op die Voëlklip-platform begin broei. Hierdie platform is blykbaar bevolk deurdat eertydse broei-eilande by Sandwich-hawe hul nut as nesmaakterreine verloor het toe hulle van die vasteland deel geword het, sodat roofsoogdiere hulle kon bykom. Die bevolking by Voëlklip het waarskynlik sedert die laat sestiger- en vroeë sewentigerjare gedaal. Omdat dit bekend is dat witpelikaankuikens die eiers en kuikens van die Kaapse trekduiker *Phalacrocorax capensis* vreet, word aan die hand gedoen dat 'n groot bevolking van Kaapse trekduikers die aanwas van witpelikane kan verbeter.

According to Siegfried *et al.* (1976), the white lican *Pelecanus onocrotalus* breeds at only two alities in the Republic of South Africa: at Lake Lucia (28° 12′S, 23°07′E) and at Dassen Island °25′S, 18°05′E). However, Berry (1975) has orted that it also breeds in the Walvis Bay lave at Bird Rock guano platform (22°53′S, 32′E). Three former breeding colonies, Seal nd in False Bay (34°07′S, 18°35′E), Dyer Island °41′S, 19°25′E) and Quoin Rock 34°47′S, 40′E), are no longer extant (Rand 1963). Siegfried *al.* (*op. cit.*) state that the number of white icans at Lake St Lucia has declined in recent rs because of degradation of the ecosystem human interference, but Berruti (1980), in a e exhaustive review, shows the population to e been more or less static in recent years. He s the current breeding population as between 00 and 2 000 pairs, which makes it South rica's most important colony. A total of 174 ite pelican nests was counted at Dassen Island 25 October 1978 (Cooper 1980). This report cuments the history of the population at the rd Rock guano platform.

Construction of the Bird Rock guano platform s commenced in 1930 and the present area of 000 m² was attained in 1939 (Berry 1975). though Berry *et al.* (1973) state that erection of e platform began in 1932 and Rand (1952) cites 35 as the date, the present manager of the platform has records of guano collection dating from 1931. We therefore accept 1930 as the year construction was initiated, and this was in fact the year given on records left by the designer and builder, Mr Winter (Berry *op. cit.*).

White pelicans were first recorded breeding at the platform in 1949 (Rand 1952), and breeding has been observed there subsequently (Berry *et al.* 1973). We can find no earlier records. At Sandwich Harbour (23°22′S, 14°29′E), many white pelicans nested on sand islands until 1947 (Berry and Berry 1975), but a number of factors resulted in these islands becoming joined to the mainland (Rand 1952), so providing access for mammalian predators, notably black-backed jackals *Canis mesomelas* (Terblanché 1980). A 1937 map of Sandwich Harbour in Terblanché *(op. cit.)* indicates a Pelican Island, so presumably white pelicans nested at Sandwich Harbour before that date. The earliest positive record we can obtain is for November 1933, from a labelled egg in the collection of H.J. Joubert, housed in the Zoology Department, University of Cape Town. The islands were present at Sandwich Harbour from about 1890 and guano was collected from 1927 (Rand 1952).

It appears that the breeding colony at Sandwich Harbour moved, probably to the Bird Rock guano platform, because by the early 1950's, white pelicans had ceased to nest at Sandwich Harbour (Rand 1952). The move probably took place about 1948,

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Table I: Estimates of numbers of white pelicans at Bird Rock platform in Walvis Bay, 1956-1978

Date	Census technique	Number		Source
		Adults	Chicks	
20 November 1956	Aerial photography	270	18	
15 November 1967	Aerial photography	1 048	32	
1969			200-400	Berry *et al.* (1973)
1970			200-400	Berry *et al.* (1973)
1971			200-400	Berry *et al.* (1973)
1974-1975		500-600		Berry (1975, personal communication)
2 January 1977	From adjacent mainland	100	60	Whitelaw *et al.* (1978)
11 January 1978	From adjacent mainland	298	81	Whitelaw *et al.* (1978)
28 November 1978	Aerial photography	372	43	
11 December 1978	From adjacent mainland	c. 250	84*	

* About 75 of the adults were in an incubating or brooding position, suggesting a total of 159 breeding pairs because whi pelicans rear only one young (Cooper 1980)

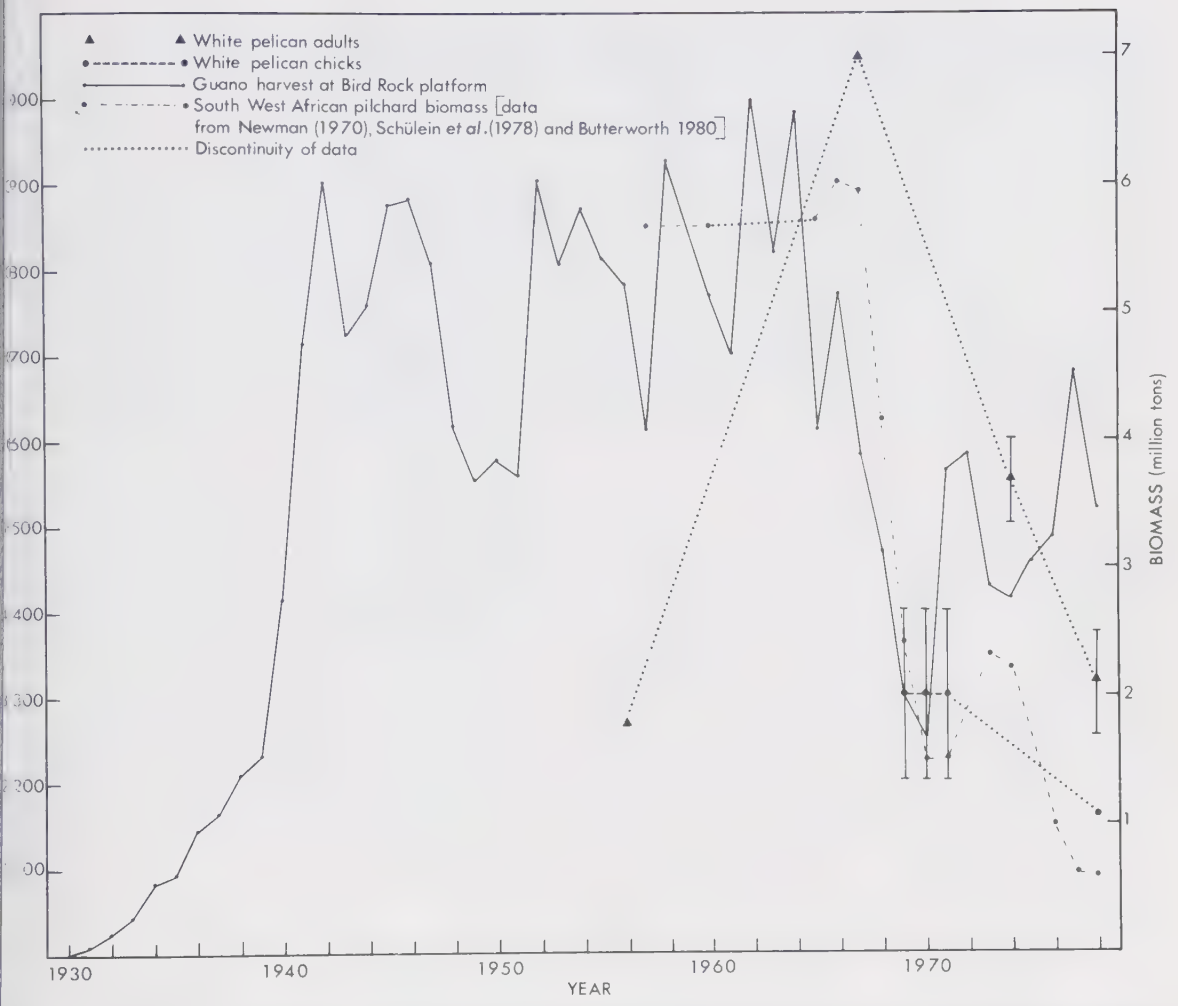
no guano being collected at Sandwich Harbour after 1947 (Terblanché 1980). Had no platform been in existence at this period, the white pelican population of Sandwich Harbour would have had difficulty in breeding along the South West African coast. It is interesting that they colonized the nearest platform, although others were in existence in Cape Cross Lagoon (Rand *op. cit.*).

Counts of white pelicans at the Bird Rock guano platform are summarized in Table I. The November 1956, 1967 and 1978 estimates were obtained from aerial photographs. The 1956 photograph was taken at some time between 10h30 and 15h30 from an Air Force survey aircraft (Rand 1963). No details are available for the 1967 photograph, but that of 1978 was taken at 16h00 from an altitude of 300 m, also from an Air Force aircraft, on ASA 200 film in a camera with 75-mm lens. The 1977 and other 1978 counts were made through a telescope from an elevated position on the adjacent mainland.

The adult white pelican population at the Bird Rock platform appears to have increased substantially between 1956 and 1967, and to have decreased subsequently (Table I). However, the trends could be the result of diurnal fluctuations in numbers. Whitelaw *et al.* (1978) give a total count of 1 452 white pelicans for the coastline between Durissa Bay (21°17′S, 13°49′E) and Sandwich Harbour during January 1977, and 115 adults were counted on an aerial photograph of the Swakopmund guano platform (22°37′S, 14°30′E) taken at 17h00 on 28 November 1978. Whit pelicans have not been known to breed at th platform, but breeding Cape cormorants *Phal crocorax capensis* are abundant (Berry 1976).

Counts of white pelican chicks hatched at Bir Rock platform would provide a better indicatio of population trends but, because chicks bein brooded would not be seen, estimates of th parameter from aerial photography are unreliabl From ground counts of chicks a decrease sinc the late 1960's and early 1970's is apparent. Berr *et al.* (1973) state that, in the three breeding season between 1969 and 1971, 200-400 chicks hatche annually whereas, taking into account adult observed in incubating or brooding positions, th estimated number for 1978 was 159.

Census figures for white pelicans at Bird Roc platform are compared with guano production a this platform and biomass estimates for the Sout West African pilchard stock in Figure 1. Guan production at many South African localities i closely related to abundance of sea birds, an at Bird Rock platform the harvest fell sharpl after 1966, coincidental with the initial decline o the South West African pilchard stock (Crawfor and Shelton 1978). It would appear, therefore that the population of Cape cormorants, the mai guano-producer at this platform (Berry 1975), wa larger in 1966 and 1967 than in subsequent years The pilchard biomass increased slightly betwee 1971 and 1973, but then declined again (Butterwort 1980). Although guano production at Bird Rock



1: Counts of white pelican adults and chicks and guano harvests at Bird Rock platform, and estimate of biomass of the South West African pilchard stock, 1930-1978

latform increased between 1974 and 1977, the mbined harvest for all South West African latforms declined rapidly after 1973 because of a rge decrease in numbers of Cape cormorants Crawford and Shelton in press). The estimated ilchard stock size for 1978 was the lowest since 957 (Butterworth *op. cit.*).

DISCUSSION

The probable decline in the population of white elicans at Bird Rock platform during the late 1960's and early 1970's appears to be related to a similar trend in that of Cape cormorants, and it may therefore have been indirectly influenced by the availability of pelagic fish in the vicinity. Off southern Africa, white pelicans seldom prey directly on shoaling marine pelagic fish. Berry (1976) observed that, at both the Swakopmund and Bird Rock platforms, pelicans are predators of the eggs and nestlings of Cape cormorants. At the latter site, predation by feathering-to-fledging pelican chicks was particularly noticeable. These chicks actively disturbed nesting Cape cormorants, snapping up eggs and chicks. At Bird Rock platform, and at Dassen Island where white

pelicans also breed in close proximity to Cape cormorants, a large population of Cape cormorants could increase the breeding success of pelicans. Conversely, over-exploitation of pelagic fish stocks could have more widespread repercussions for avian populations than previously recognized.

ACKNOWLEDGEMENTS

We are grateful to Dr R. W. Rand of the Department of Nature and Environmental Conservation of the Cape Provincial Administration and Dr H. H. Berry of the Etosha Ecological Institute for reviewing the manuscript.

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REPORTED RED-WATER OUTBREAKS AND THEIR EFFECTS ON FAUNA OF THE WEST AND SOUTH COASTS OF SOUTH AFRICA, 1959-1980

D. A. HORSTMAN

Red-water outbreaks in South Africa between 1959 and 1980 are listed. Of the 14 species responsible for these outbreaks, two were evidently toxic, *Gonyaulax catenella* and *G. grindleyi*. Seasonal trends, geographical occurrence and environmental relationships are reported on, and paralytic shellfish poisoning and faunal mortalities documented. Full descriptions of the sampling carried out and some information on previously undocumented outbreaks are given.

Die rooiwateropbloeiings in Suid-Afrika tussen 1959 en 1980 word aangestip. Van die 14 spesies wat vir hierdie opbloeiings verantwoordelik was, was twee, naamlik *Gonyaulax catenella* en *G. grindleyi*, klaarblyklik giftig. Daar word verslag gedoen van seisoentendense, geografiese voorkoms en omgewingsverhoudinge, en paralitiese skulpvisvergiftiging en dierevrektes word gedokumenteer. Volledige beskrywings van die bemonstering wat gedoen is, en sommige resultate van voorheen ongedokumenteerde opbloeiings word gegee.

Red water is a natural phenomenon caused by nse concentrations of unicellular organisms ich colour the ocean brown, orange, red or rple. Autotrophic and heterotrophic dinogellates and ciliates are generally responsible r red-water outbreaks off the west and south sts of South Africa (Figs. 1 and 2).

The majority of organisms that cause red water non-toxic. However, they may have an adverse ect on the marine fauna and its environment ough secondary complications such as gill gging, hyperoxia, oxygen embolism and hypoxia anoxia (Grindley and Taylor 1964, Brown *et al.* 9).

The nerves of certain bivalves are resistant to blocking effects of saxitoxin (S.T.X.), an active nciple of paralytic shellfish toxin. S.T.X. blocks duction of the nerve impulse by reversibly erfering with the early voltage-dependent rease in sodium ion conductance, which erates the nerve action potential (Narahashi d Moore 1968). This conductance block leads paralysis. Filter-feeding molluscs which ingest xin-producing dinoflagellates accumulate the ison and, when they are eaten by humans and imals, cause paralytic shellfish poisoning .S.P.).

Signs and symptoms of P.S.P. in humans have en described by Meyer (1953) and by Popkiss *et* (1979) and are briefly outlined here. Lips, tongue d finger tips gradually become numb within a w minutes of eating contaminated shellfish. mbness of the arms, legs and neck and a general uscular incoordination associated with respiratory stress follows. Death from respiratory paralysis n occur within 2—24 hours, depending on the antity of toxin ingested.

P.S.P. has been diagnosed in many parts of the world, the first records being from almost 300 years ago. Halstead (1965) listed over 900 cases of P.S.P., including over 200 human fatalities, as occurring world-wide between 1689 and 1962. Prakash (1975) reported 1 600 cases, including 300 fatalities, the majority of which were in subtropical and tropical zones. The incidence of P.S.P. in South Africa, including documented proof of six human fatalities, was reviewed by Grindley and Nel (1970).

Industrial development along the west coast of South Africa during the last few decades has led to a population increase, and greater efforts are gradually being directed towards both predicting red-water outbreaks and monitoring toxicity levels in edible filter-feeders.

The aim of this report is to assemble as much as possible published and unpublished information on local red-water occurrences, so that it may be used as a basis for further research on the phenomenon. In addition, several red-water outbreaks, some of which had adverse effects on the environment, are described in detail. The organisms responsible for these outbreaks were *Mesodinium rubrum* and *Gonyaulax catenella*. The uncertainty surrounding the toxicity of *Gonyaulax grindleyi* is also discussed.

METHODS

Collection of data

Inspectors of the Sea Fisheries Institute, stationed at various localities along the coastline routinely

Fig. 1: Bloom of *Noctiluca miliaris* in False Bay (taken with polarizing lens)

Fig. 2: Bloom of *Gonyaulax catenella* at Elands Bay, March 1980

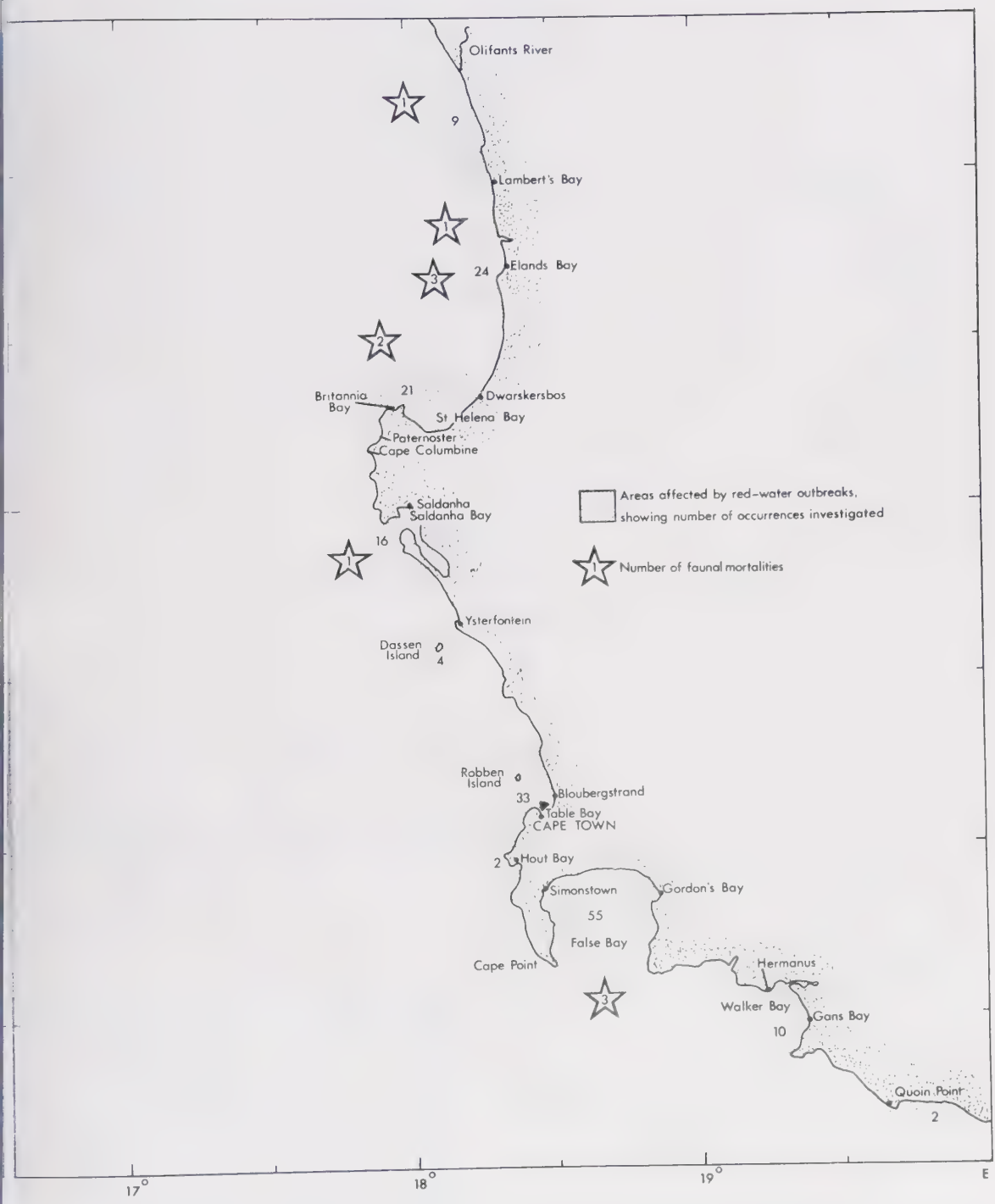


Fig. 3: Locations and summary of reported outbreaks, 1959-1980

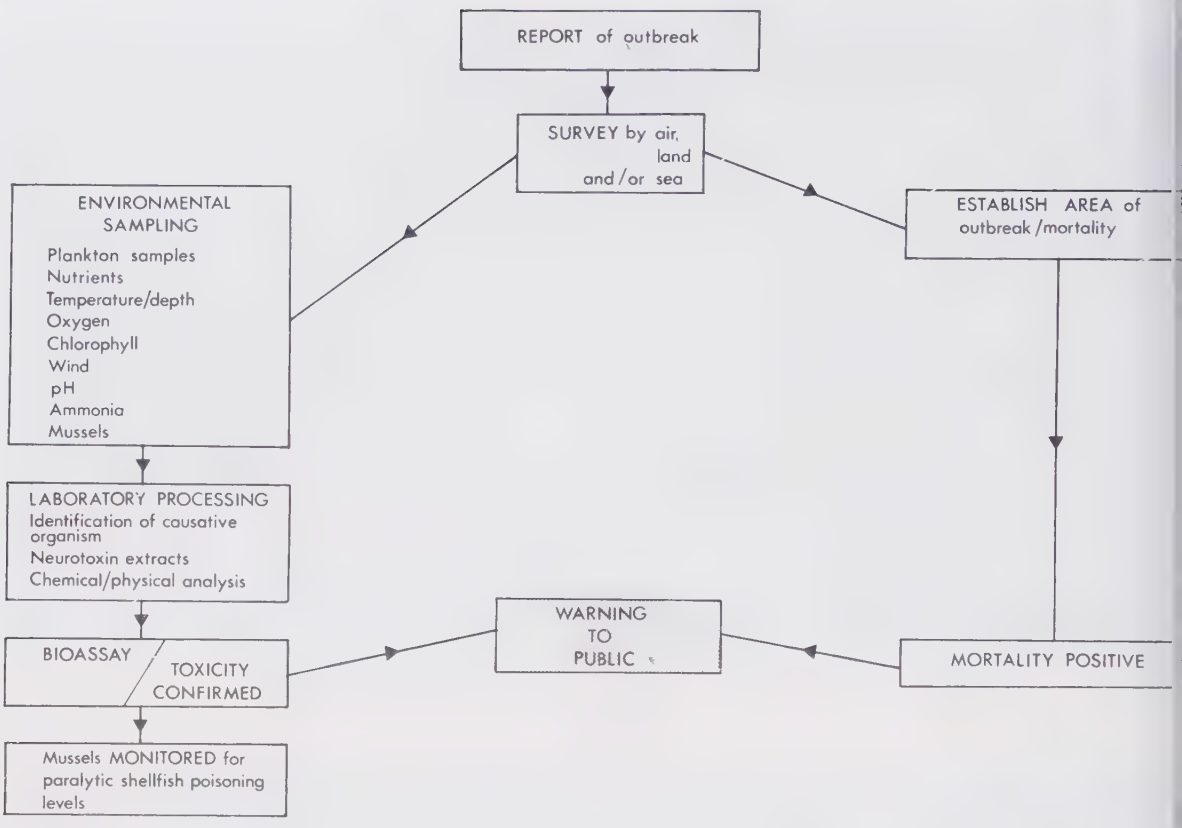


Fig. 4: Action taken by the Sea Fisheries Institute during red-water outbreaks

report red-water outbreaks (Fig. 3) to the laboratories in Cape Town. They collect water samples (preserved with 5-per-cent formalin) and record the sea surface temperature and colour, and the location and extent of the affected area. If feasible, an unpreserved water sample is also taken. Weather conditions and any abnormalities, including faunal mortalities, are also reported.

When outbreaks are very large or are caused by toxic organisms which may have adverse effects on the environment and/or cause P.S.P. in man, a more detailed investigation is conducted. The usual plan of action is shown in Figure 4. Water samples are drawn from the required depth by means of a 5-ℓ National Institute of Oceanography (N.I.O.) bottle and are used for salinity, oxygen, phosphate, nitrate, silicate and chlorophyll determination and for phytoplankton identification. Sea surface samples are sometimes taken using a bucket. Water colour, bioluminescence and any faunal abnormalities either at sea or on the shore are noted Wind data are collected from nearby lighthouses where one is situated conveniently.

Toxicity tests

Bioassays of red-water material, as described b Prakash *et al.* (1971), are performed by the Stat Department of Health with extracts of one c more of phytoplankton samples, bivalves or roc lobsters. Extracts are injected intraperitoneall into mice and median death times are converte to microgrammes of toxin per 100 grammes c tissue. Concentration of toxin, expressed in mous units $\cdot 100\ g^{-1}$, are usually of the order of four time the determined level in $\mu g \cdot 100\ g^{-1}$. One mous unit (M.U.) is defined as the quantity that will kil a 20-g female white mouse in 15 minutes.

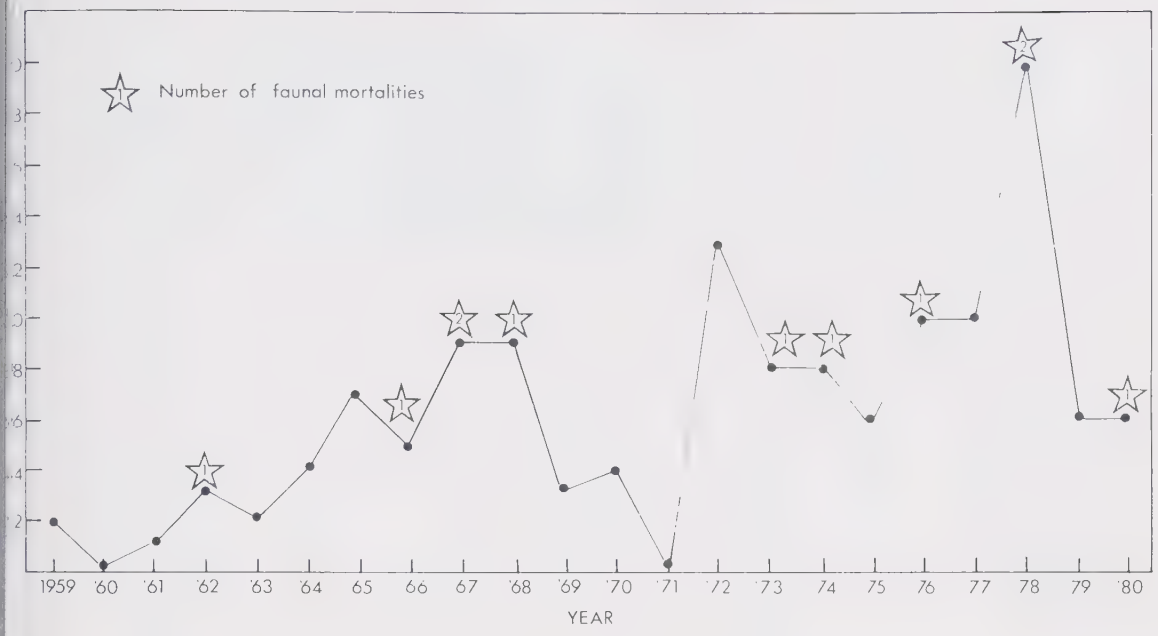


Fig. 5: Annual number of outbreaks, 1959-1980

RED WATER IN SOUTH AFRICA

breaks and their causes

uring the past 21 years, 177 red-water outbreaks e been reported between the Olifants River Quoin Point (Fig. 3). Most were from the ely populated areas of False Bay and Table and, to a lesser extent, from Saldanha Bay St Helena Bay. The general increase in the ber of reported outbreaks per year (Fig. 5) not necessarily reflect an actual increase in water blooms, but may be the result of greater reness among the local populace of what red er is and what are its associated hazards. This reased awareness has probably come about ause of more explicit documentation in the ss media.

The monthly incidence of outbreaks (Fig. 6) ws that red water is most common in late mmer, autumn and early spring. The relatively outbreaks during late spring and early summer y be related to the prevailing south-easterly nds, which result in extensive upwelling and nce in an unstable mixed layer along the West ast (Andrews and Hutchings 1980). The absence regular south-easterly winds in autumn coupled

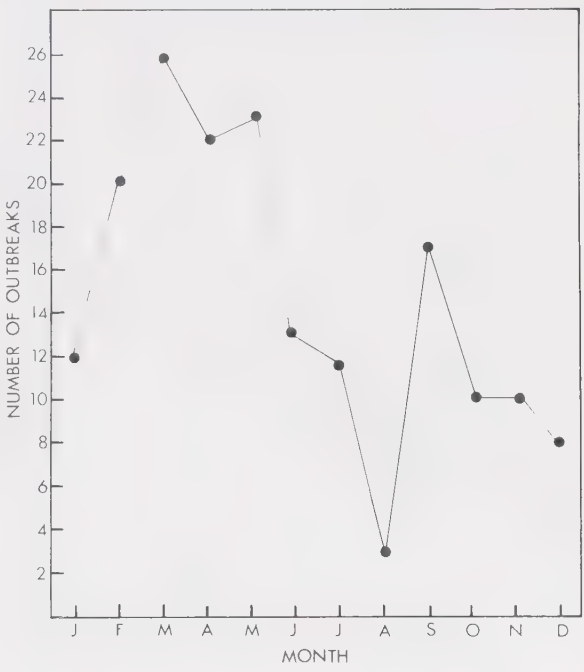


Fig. 6: Monthly reported occurrence of red water (all species), 1959-1980

Table I: Species responsible for red-water outbreaks in South Africa, 1959-1980

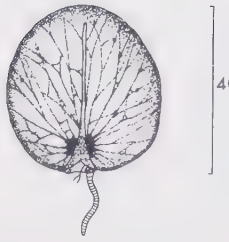
Organism	Temperature	Bloom colour	Luminescence	Toxic	Area	Monthly or seasonal occurrence	Total number of occurrences	Notes
Noctiluca miliaris	range: 11-22°C opt. 17-22°C	Orange	Yes	No	Lambert's Bay to Quoin Point. Mainly False Bay	All months except Dec., Jan. Peak: Sep., Feb. -Apr.	57	Large (up to 1 200 μm) dinoflagellate. Holozoic (Newell and Newell 1977).
Mesodinium rubrum	range: 13-17°C opt. 14-15°C	Deep maroon	No	No	Lambert's Bay to Gans Bay. Mainly St Helena and Table Bays	All months except Aug. Peak: Jan., May	40	Holotrich ciliate responsible for red water in many coastal areas of the world (Taylor and Blackbourn 1971).
Prorocentrum micans	range: 13-20°C	Brown	No (Sweeney 1963)	No	Lambert's Bay to Gans Bay	All months except Jun. More common during spring, summer, autumn	29	Cosmopolitan armoured dinoflagellate common in coastal waters (Cupp 1943, Abé 1967).
Peridinium trochoideum	14.9°C (one recording)	—	—	No	Elands Bay to False Bay	Autumn and spring	9	Neritic dinoflagellate, commonly associated with red-water outbreaks in South West African waters (Pieterse and Van der Post 1967).
Ceratium furca	range: 16-18°C	—	No	No	Elands Bay to Gans Bay	Mainly Feb., Apr.	8	Common around the coast of South Africa both inshore and off shore (Sea Fisheries Institute, unpublished data).
Gonyaulax spinifera	range: 14-19°C	—	—	No	Mainly False Bay, but also St Helena Bay area and Gans Bay	Jan.-Apr.	6	A little-known species, described by Wood (1968) as either neritic or oceanic.

— not known or not observed

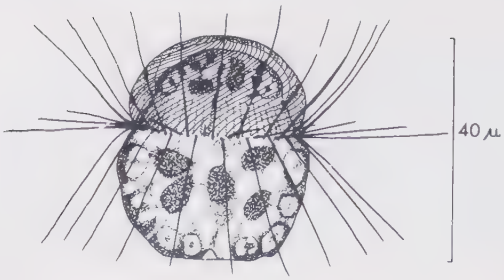
Table I: Species responsible for red-water outbreaks in South Africa, 1959-1980 (continued)

Organism	Temperature	Bloom colour	Luminescence	Toxic	Area	Monthly or seasonal occurrence	Total number of occurrences	Notes
G. polygramma	range: 15-20°C	Red/brown	Yes (Sweeney 1975)	No	False Bay	Feb.-Apr.	5	Armoured dinoflagellate favouring warm water.
G. catenella	up to 20°C	Brown	Yes (Hashimoto 1976)	Yes	Saldanha Bay, Elands Bay	Dec.-Mar.	5	Chain-forming armoured dinoflagellate (Whedon and Kofoid 1936). Is extremely toxic, causes P.S.P. (Sommer and Meyer 1937). Hashimoto (1976) found the yield of toxin to be ± 1 mouse unit per 40 000 cells.
G. grindleyi	range: 17,5-19°C	Dark red	—	Yes	Lambert's Bay to Elands Bay, Bloubergstrand	Spring and summer	2	New species described by Reinecke (1967). Armoured dinoflagellate, most probably causes P.S.P.
Gymnodinium splendens	—	—	—	No	Saldanha Bay, Table Bay	Autumn	2	—
G. arcuatum	14,5°C	—	—	No	Elands Bay, St Helena Bay	Mar.	1	—
Gymnodinium sp.	range: 14,9-15,6°C	Dark brown	—	No	False Bay (Gordon's Bay)	Aug., Sep.	1	Unarmoured dinoflagellate
Dinophysis acuminata	18,5°C, 19°C	Red/brown	—	No	Elands Bay, St Helena Bay	Mar.	2	—
Peridinium minutum	—	Red/brown	—	No	St Helena Bay	Feb.	1	—

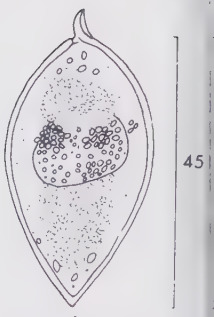
— not known or not observed



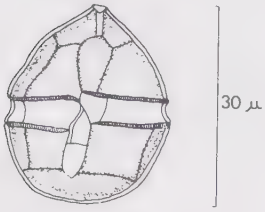
Noctiluca miliaris
(from Schiller 1933–1937)



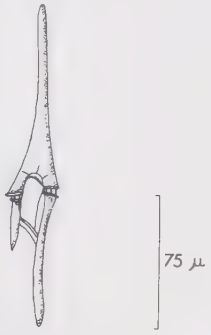
Mesodinium rubrum
(from Taylor *et al.* 1969)



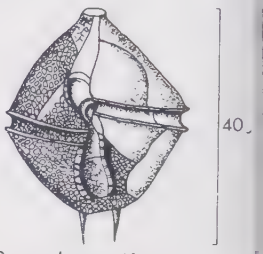
Prorocentrum micans
(from Abé 1967)



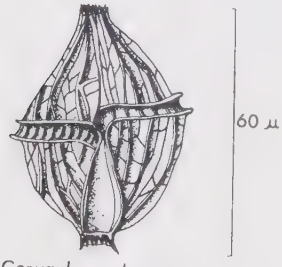
Peridinium trochoideum
(from Taylor 1976)



Ceratium furca v. berghii
(from Schiller 1933–1937)



Gonyaulax spinifera
(from Schiller 1933–1937)



Gonyaulax polygramma
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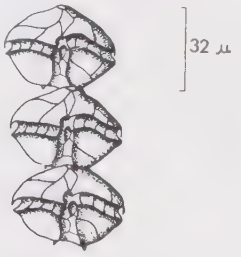
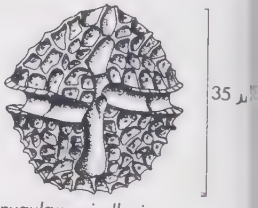
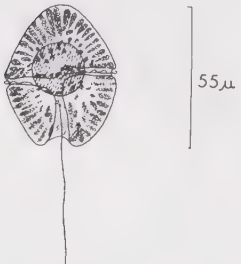


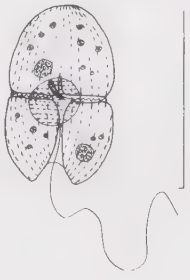
Gonyaulax catenella
(from Whedon and Kofoid 1936)



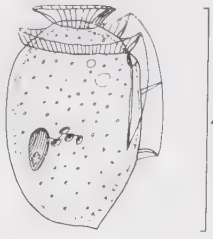
Gonyaulax grindleyi
(from Grindley and Nel 1970)



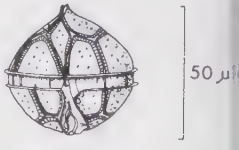
Gymnodinium splendens
(from Schiller 1933–1937)



Gymnodinium arcuatum
(from Schiller 1933–1937)



Dinophysis acuminata
(from Schiller 1933–1937)



Peridinium minutum
(from Schiller 1933–1937)

Fig. 7: Thirteen identified species that caused red-water blooms in South Africa, 1959-1980 (one dinoflagellate *Gymnodinium* sp., could not be identified to species level — Brown *et al.* 1979)

Table II: Dinoflagellate species causing P.S.P. and/or faunal mortalities, 1959-1980

e of reak	Species	Effect	Location	Mortality	Reported by
-Apr.	*Gonyaulax polygramma*	Gill clogging	False Bay	More than 100 tons of inshore fish and invertebrates. Concentration $12,0 \times 10^6$ cells$\cdot\ell^{-1}$	Grindley and Taylor (1964)
-Jan. /67	*Gonyaulax grindleyi*	P.S.P.	Elands Bay	Large quantities of black and white mussels, also sea birds. Mussels remained toxic for four months. Concentration $6,0 \times 10^6$ cells$\cdot\ell^{-1}$	Grindley and Nel (1970)
1974	*G. grindleyi*	P.S.P.	Elands Bay	Huge quantities of black and white mussels. Within 10 days large quantities of black mussels washed out at Bloubergstrand. Mussels along West Coast (Bloubergstrand and Lambert's Bay) remained toxic for 6 months. Concentration $2,0 \times 10^6$ cells$\cdot\ell^{-1}$	This report
1967	*G. catenella*	P.S.P.	Elands Bay to north of Olifants River	Huge quantities of black and white mussels, also large quantities of rock lobsters, hagfish, sucker fish, octopuses and some sea birds. Concentration 40×10^6 cells$\cdot\ell^{-1}$	This report
1968	*G. catenella*	P.S.P.	Elands Bay, Lambert's Bay	Large quantities of black and white mussels. Concentration $1,14 \times 10^6$ cells$\cdot\ell^{-1}$	Grindley and Sapeika (1969)
1978	*G. catenella*	P.S.P.	Saldanha Bay	Huge quantities of black and white mussels, sea birds.	Popkiss *et al.* (1979)
1980	*G. catenella*	P.S.P.	Elands Bay	Huge quantities of black and white mussels, also sea birds.	This report
-Sep.	*Gymnodinium* sp.	Gill clogging	False Bay (Gordon's Bay)	Hundreds of inshore fish	Brown *et al.* (1979)
1978	*Mesodinium rubrum*	Hypoxia	St Helena Bay	Many hundreds of rock lobsters, angelfish, butterfish, barbel, hottentot, kingklip, sucker fish, hagfish, silverfish, trumpeter, guitar shark, striped shark, spotted lazy shark, and thousands of sea urchins.	This report
1973	*Prorocentrum micans*	Slight P.S.P.	Dwarskersbos	Relatively large quantities of white mussels.	Toxicity reported by Pinto and Silva (1956)
1967	*Noctiluca miliaris*	Secondary effects, possibly ammonia (Okaichi and Nishio 1976)	False Bay (Simonstown)	Small localized mortality of inshore fish ($\pm$ 100 fish). Species affected were mackerel, hottentot, mooinooientjie, steentjie and various sharks.	Unpublished

h limited upwelling and warm calm days features which may contribute to the high inence of red-water blooms during this period. ailable records suggest a strong link between nd patterns and red-water outbreaks. Strong uth-easterly winds (15-20 $m \cdot s^{-1}$) lasting between and 10 days are often followed by 2-3 days of m weather, allowing stabilization of the water lumn and subsequent production of red water.

ecies responsible for red-water blooms

The 14 species found to be responsible for red ter in South Africa are illustrated in Figure 7 and listed in Table I with the frequency of reported occurrence, location and other associated information. Only *Gonyaulax catenella* and *G. grindleyi* were found to be consistently toxic. During November 1973, white mussels *Donax serra* at Paternoster were found to be toxic after a bloom of *Prorocentrum micans*, leading to the conclusion that this species could be a possible source of toxin. A similar incidence of this species' toxicity has been recorded on the west coast of Portugal by Pinto and Silva (1956) but, because it is only irregularly toxic in South Africa (Tables I and II), for the purposes of this report it is considered to be normally non-toxic. Red-water species that caused mass faunal mortalities are listed in Table II.

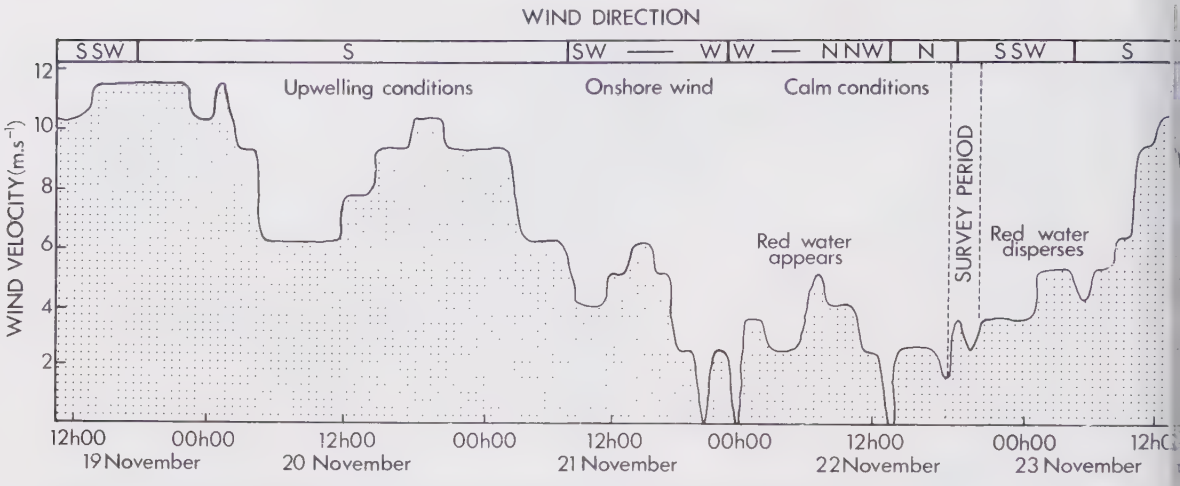


Fig. 8: Hourly wind speed and direction at Cape Columbine, 62 km south of Elands Bay, November 1977

NON-TOXIC RED-WATER BLOOMS

Two large outbreaks of the non-toxic red-water ciliate *Mesodinium rubrum* took place in November 1977 and April 1978, the latter incidence resulting in extensive faunal mortality through secondary affects.

Elands Bay — November 1977

A steady southerly wind (± 15 m•s^{-1}) that lasted for seven days resulted in extensive upwelling at Elands Bay (Fig. 8). Subsequent calm hot weather resulted in the formation of a strong, shallow thermocline at 5-8 m (Fig. 9) coincident with the appearance of red water on 22-23 November. Results of a brief survey are listed in Table III. Relatively high surface temperatures of 14-15°C coupled with low salinity levels (34,67-34,69‰) indicated sun-warming of newly upwelled water (Andrews and Hutchings 1980). Chlorophyll concentrations were very high near the sea surface, but decreased below the thermocline (at 14 m) at station 2, about 300 m from the shore, in sympathy with the total cell counts.

M. rubrum occurred together with, but was completely dominated by, the most common diatom on the West Coast, *Skeletonema costatum*. Although *M. rubrum* comprised only 5 per cent of the total phytoplankton population at station 1, it was sufficient to discolour the water a deep maroon. McAlice (1968) reported that discolouration by the species is detectable at 2×10^5 cells ℓ^{-1} and strong at 2×10^6 cells•ℓ^{-1}. Because of its strong phototactic response (Bary and Stucke 1950), it was not surprising that *M. rubrum* was absent below the thermocline. As stated by Fonda and Eisma (1967), blooms of *M. rubrum* closely follow upwelling.

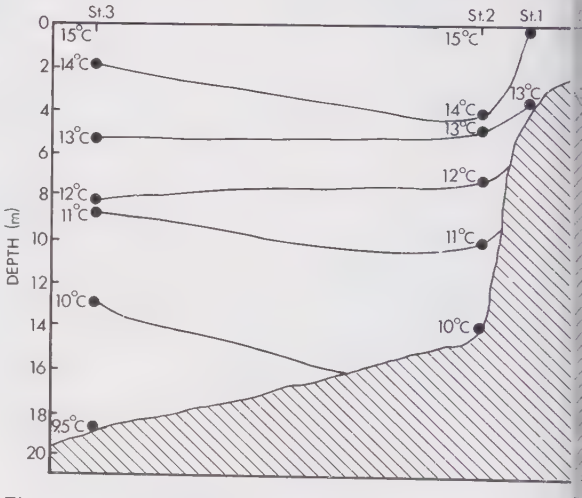


Fig. 9: Vertical temperature section along the line o stations, November 1977

St Helena Bay — April 1978

For the first time in South Africa, *M. rubrum* was found to be responsible for mortalities of fish

e III: Hydrobiological parameters recorded at Elands Bay on 22 November 1977 at two stations

robiological meter	Value recorded			
	Station 1 (at the jetty)	Station 2 (300 m off shore)		
h (m)	0	0	5	14
perature	14	15	13,0	10,3
ity (‰)	34,68	34,68	34,68	34,69
rophyll *a* m^{-3})	123,40	16,81	38,92	3,47
rophyll *b* m^{-3})	3,13	0,30	1,48	1,18
rophyll *c* m^{-3})	42,30	6,94	15,42	2,42
al rophyll m^{-3})	168,84	24,05	55,82	7,49
etonema tum	38 033 524	18 516 759	22 749 090	42 500
dinium um	2 100 000	333 000	666 670	0
l cells•ℓ$^{-1}$	42 399 874	18 883 393	24 099 096	42 500
te •ℓ$^{-1}$)	11,1	2,8	4,2	38,9
te •ℓ$^{-1}$)	1,8	0,4	2,7	14,9
ive hate •ℓ$^{-1}$)	3,4	0,8	1,1	3,3
gen (mℓ•ℓ$^{-1}$)	9,97	8,90	9,08	3,30

Table IV: Range of hydrobiological parameters recorded at St Helena Bay at stations 1 (inside kelp bed) and 2 (outside kelp-bed zone), 6 and 7 April 1978

Parameter	Range from surface to bottom
Temperature (°C)	15,40 — 14,30
Salinity (‰)	34,59 — 34,70
Total chlorophyll (mg•m^{-3})	12,96 — 3,20
Silicate (μg-at•ℓ$^{-1}$)	53,2 — 24,6
Nitrate (μg-at•ℓ$^{-1}$)	9,0 — 1,0
Reactive phosphate (μg-at•ℓ$^{-1}$)	18,2 — 2,8
pH	7,54 — 8,46

invertebrates during April 1978. The red water observed at St Helena Bay on 1 April. During following two days, large numbers of rock lobrs *Jasus lalandii* and sea urchins and hundreds fish and sharks were washed up on the beach. e weather was hot, the sea was calm and the l water extremely conspicuous.

A short survey on the evening of 4 April revealed t. during the afternoon, a 15 m•s^{-1} southerly d caused upwelling of clear water which pushed red water approximately 100 m off shore. rticularly noticeable were the large numbers of e but moribund rock lobsters exposed on the cks.

As the concentration of dissolved oxygen in the sea water was high, asphyxiation as a result of oxygen depletion was excluded as the cause of the mortality. It is possible, however, that clogging of the fish gills and coating of the urchin respiratory surfaces by the dense concentrations of the ciliate caused distress amongst the animals.

The survey was terminated because strong offshore winds seemed likely to return conditions to normal. However, by the next morning (5 April) the wind had dropped and an aerial survey showed that red water extended from Elands Bay to Dassen Island (see Fig. 3) with the densest concentrations in St Helena Bay. Off-shore patches had the familiar maroon colour, whereas the red water close inshore was more brown (Figs. 10, 11).

St Helena Bay was revisited at 18h00 on 6 April. Signs of continued faunal mortality were found and live rock lobsters were again observed on the rocks. Results of the survey are summarized in Tables IV and V.

Decomposition of the fauna which succumbed

Table V: Changes in dissolved oxygen concentration at stations 1 and 2 at St Helena Bay, 1978

Depth (m)	Oxygen concentration (mℓ•ℓ$^{-1}$)			
	6 April		7 April	
	Stn 1	Stn 2	Stn 1	Stn 2
0	1,09	7,33	3,40	4,57
2	1,60	7,33	3,21	4,56
4	2,00	7,36	3,07	4,67
6		6,24		5,24
8		4,66		3,20
10		4,35		3,79

Fig. 10: A healthy bloom of *Mesodinium rubrum*

Fig. 11: *Mesodinium rubrum* in the process of decaying

Fig. 12: Mass mortality of white mussels at Elands Bay, March 1980

ring the initial stages of the red-water outbreak s probably responsible for the low oxygen levels able V) on 6-7 April which, in turn, caused the nal mortalities during the latter stages of the break. The reason for the extremely high active-phosphate and silicate concentrations is t understood. The oxygen values recorded in ble V were taken both inside the kelp bed tion 1) and immediately outside the kelp zone tion 2). The effect of a southerly wind on 7 ril was to cause a slight recovery of the oxygen ntent of the water at station 1 and to displace low-oxygen water farther off shore.

The difference in colour of the bloom between f shore (maroon) and inshore (brown) was cause the off-shore bloom was healthy whereas shore it was decaying.

TOXIC RED-WATER BLOOMS

onyaulax catenella

The well-known toxic dinoflagellate *G. catenella* as responsible for four of the red-water outbreaks ported during the last 21 years (Table II).

The first of these four outbreaks, on 28 December 1967, covered an area from Elands Bay to north of the Olifants River, and was first noticed at Elands Bay after two weeks of continuing southerly winds. The water remained discoloured until 28 January 1968, temperatures reaching 20°C and brilliant fluorescence being observed at night. Counts of 40×10^6 cells$\cdot \ell^{-1}$ were recorded.

Thousands of black mussels *Choromytilus meridionalis* and white mussels were washed up onto the beach, destroying virtually the entire adult mussel population. Toxicity tests showed that black and white mussels and the digestive glands, though not the flesh, of rock lobsters were toxic. Six years later there was still no sign of any recovery in the white-mussel population (De Villiers 1975).

The second outbreak, at Elands Bay in December 1968, and the third, at Saldanha Bay in May 1978, are described by Grindley and Sapeika (1969) and by Popkiss *et al.* (1979) respectively.

The fourth outbreak occurred on 4 March 1980, when dense red water (23×10^6 cells$\cdot \ell^{-1}$) was reported at Elands Bay (Fig. 2). About 5 million white mussels were washed up onto the beach the following day (Fig. 12) from the three mussel beds at Elands Bay alone, but the total area affected

Table VI: Toxicity levels of black mussels (whole animals) and rock lobsters (digestive glands only) collected at Elands Bay, 7 March 1980

Collection depth (m)	Toxicity (μg toxin • 100 g⁻¹ tissue)	
	Rock lobsters	Black mussels
0	Not present	465,0
5	400	9 784,1
10	459,4	2 657,3
15	288,7	Not present
20	Not present	Not present

Table VII: Toxicity levels of whole mussels at monitorin sites, March-May 1980

Site	Toxicity levels (μg toxin • 100 g⁻¹)		
	March	April	May
Lambert's Bay	1 261,3	465,0	<80
Elands Bay	3 229,6	1 098,4	107,3
Dwarskersbos	1 281,6	626,6	<80
Britannia Bay	<80	<80	<80
Ysterfontein	<80	<80	<80

was from Dwarskersbos to Lambert's Bay (see Fig. 3). Several dead or paralysed sea birds were also seen. Up to 6 March only adult white mussels were affected, but on 7 March small white mussels were found lying paralysed on the beach. On 7 March, 80ℓ of red water and specimens of black and white mussels and rock lobsters were collected for toxicity tests. Also, some rock lobsters from the holding tanks of the commercial concerns in the area were removed for testing.

Because no information is available on the vertical migration of *G. catenella* and therefore on the depth at which black mussels (the staple diet of rock lobsters) would be affected, rock lobsters and black mussels were collected at a series of depths. The red-water sample was concentrated by filtration (37 μm mesh) to 500 mℓ and extracts were made from the concentrate, from the mussels and from the rock-lobster digestive glands. During the concentration process, the filtrate took on a pinkish colouration accompanied by a strong smell.

Bioassays on the extracts revealed that the toxicity of the red-water concentrate and the filtrate were 286,1 and 918,1 μg toxin • 100 g^{-1} respectively, indicating a considerable leaching of toxin into solution. The toxicity of ten rock lobsters collected at the factories was 972,6 μg toxin • 100 g^{-1} of digestive gland. A summary of the toxicity tests on rock lobsters and mussels collected at the different depths is given in Table VI. Highest toxicity of rock lobsters was found in specimens collected at 10 m, and of black mussels in individuals collected in 5 m of water.

The rate of decrease in shellfish toxicity is variable (Table VII) and appears to follow no set pattern, taking between one month and six months for all toxin to be eliminated (Grindley and Nel 1970, Popkiss *et al.* 1979). Prakash *et al.* (1971) suggest that a direct relation exists between the rate of poison release and water temperature, release being slower at low temperatures.

Gonyaulax grindleyi

This species was recorded for the first time by Grindley and Nel (1970) at Elands Bay in December 1966/January 1967 in association with a mass mortality of black and white mussels. The species was described as being non-toxic and the mortality and toxicity of the mussels was attributed to *G. catenella*, a few cells of which were found in offshore samples.

In September 1974, a second bloom of *G. grindleyi* took place, but this time the outbreak was widespread along the West Coast. Less than 24 hours after the red water was first seen, black and white mussels began to wash up onto the beach. About half were found to be paralysed, the others dead. The concentration of *G. grindleyi* was 2×10^6 cells • ℓ^{-1} and, although associated with *Peridinium trochoideum* and to a lesser extent with *Prorocentrum micans*, it was clearly dominant. No trace of *G. catenella* was found. Mussels along the West Coast remained toxic for six months.

From the evidence obtained during the September 1974 outbreak, *G. grindleyi* seems to be classifiable as a toxic species, but further information on monospecific blooms is necessary for confirmation.

Grindley and Nel (1970) tried to extract the toxin directly from the cells of *G. grindleyi* in 900 mℓ of red water containing a total of approximately $5,4 \times 10^6$ cells. The toxicity tests on the centrifugate were negative. A similar test was done during the 1980 outbreak of *G. catenella*, when $1\ 840 \times 10^6$ cells only yielded a toxicity of 286,1 μg • 100 g^{-1}. Prakash *et al.* (1971) demonstrated progressive release of water-soluble toxin from cells into the surrounding medium, and the pinkish water mentioned earlier for the 1980 *G. catenella* outbreak appears to be evidence of this progressive tendency. The toxin is probably present in the cytoplasmic fluid and the latter is released from the rupturing cells during the concentrating

Fig. 13: Mortality of black mussels at Bloubergstrand caused by *Gonyaulax catenella*, May 1978

cedure. Grindley and Nel (1970) did not state ether the cells were alive when they were cessed or if they were damaged during trifuging.

ACCUMULATION OF TOXIN

Toxic red-water outbreaks in South Africa are ways associated with paralytic shellfish poisoning, sulting in heavy mortalities among filter-feeding ack mussels *Choromytilus meridionalis* and white ssels *Donax serra* along the West Coast (Figs. , 13) The bivalves accumulate the poison in eir digestive glands but may not die as a direct sult. Suffering paralysis, many are washed up nto the beaches where they die from exposure ig. 14), but death does not necessarily occur if e mussels remain submerged.

The highest toxicity levels (9 784,1 μg toxin·100 g^{-1}) ever recorded in South Africa were from live black mussels collected at a depth of 5 m (Table VII). These mussels would probably be toxic to any animal, including man, that might ingest them.

The only reference to the deleterious effects of paralytic shellfish toxin on bivalves appears to have arisen from the 1968 bloom of *G. tamarensis* off the cost of England (Adams *et al.* 1968, Ingham *et al.* 1968). Both morbidity and mortality of shellfish were associated with that bloom.

Adult mussels have been proved to be capable of filtering up to 20 ℓ of water per day (Jørgenson 1966). An adult mussel in continuous contact with red water could ingest 3,0 g dry weight of *G. catenella* in 24 hours, which would mean that the mussel could contain as much as 180 mg of toxin. Any toxin value greater than 80 μg toxin · 100 g^{-1} can be regarded as unsafe, and human consumption of such material should be discouraged. According to Prakash *et al.* (1971) and Schantz *et al.* (1975),

Fig. 14: White mussel paralysis (note distended feet)

the poison is 50 times stronger than the paralytic poison curare and as little as 0,5 mg or 3 000-5 000 mouse units of purified poison can be fatal to man.

DISCUSSION

Blooms of both toxic and non-toxic dinoflagellates occur frequently, but irregularly, along the west coast of South Africa, and only when wind-driven upwelling is inactive for at least a few days. Active upwelling usually results in diatom blooms as the upwelled waters mature. Although dinoflagellates have motility as an advantage over diatoms, turbulence counteracts the sinking rate of diatoms along the West Coast, allowing diatoms to prevail because of their more rapid growth rates (Provasoli 1979). When wind-induced turbulence is weak and stratification of the upper layers is strong, dinoflagellates may accumulate at or near the sea surface forming visible patches. Co-existence (e.g. Elands Bay, November 1977) occurs when intermediate or alternating upwelling and quiescent conditions prevail.

Although upwelling can take place throughou the year off the South-Western Cape, it is mo common during spring, summer and autum (Shannon 1966, Andrews and Hutchings 198 the seasons of the most frequent red-water bloom As there is limited river run-off during this perio it is likely that the organic substances necessa for "priming" red-water outbreaks (Barber 197 may be derived from senescing diatom blooms.

Upwelling also brings resting cysts of din flagellates into the euphotic zone. Dale *et al.* (197 found toxicity levels in *Gonyaulax excavata* cys to be at least 10 times higher than in mobi stages. Being non-mobile, the cysts settle on th sediment substrate, surviving for several montl or years. This encysting stage enables the organis to bloom repeatedly in the same area (Dale *et a op. cit.*).

Although the effects of the toxin on man ar invertebrates are well documented, the effects c invertebrates are less well understood, but the appear to result in partial or complete paralysis muscle tissue. In the absence of detailed chemic and pharmacological studies on the toxins produce by *G. catenella* and *G. grindleyi* in South Afric it is assumed that similar toxins to those describe

other *Gonyaulax* species occur here.

The unusually high mortality rates among local ssel populations may be attributed to the osed nature of the shoreline along the West ast. The heavy surf action over most of the r results in the stranding of both black and ite mussels after paralysis. Elsewhere in the rld, such stranding appears to be uncommon. Wherever mortalities occur, a drastic and tracted change in the population structure of sub- and intertidal mussels results and many rs may pass before there is a return to what y be considered a normal population (De Villiers 79).

ACKNOWLEDGEMENTS

wish to thank the Sea Fisheries' inspectors for porting red water, collecting samples and for istance given during surveys. I am also grateful numerous colleagues who assisted in collection d processing of data. I am further indebted to J. W. Louw and Mr D. Harpur of the Depart- nt of Health for performing the toxicity tests. ally, I would like to thank Miss P. C. Brown, L. Hutchings and Messrs A. I. L. Payne, I. iger and C. Sapsford for their constructive criti- m of the manuscript, and Mr A. P. van Dalsen illustrating the thirteen species.

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ANALYSIS OF PROTEIN AND CARBOHYDRATE IN PARTICULATE MATTER

R. G. BARLOW and M. J. SWART

Modifications to published methods of determining protein and carbohydrate in particulate matter are described. Samples were collected on glass-fibre filters and preserved by freeze-drying. For protein analysis, dry filters were extracted twice with 0,1N sodium hydroxide at 80°C for 10 minutes and the protein precipitated with 10-per-cent trichloroacetic acid in the presence of 1 mg of sodium deoxycholate. The precipitated pellet was then reacted with Folin-Ciocalteu reagent according to the procedure of Lowry *et al.* (1951). Carbohydrates were fractionated into acid-soluble, alkali-soluble and insoluble fractions. The carbohydrate content in each fraction was determined by the phenol-sulphuric acid method of Dubois *et al.* (1956) and total carbohydrate calculated as the sum of the three fractions. The accuracy of the methods and the reasons for introducing the various modifications are discussed.

Aanpassings in gepubliseerde metodes vir die bepaling van proteïen en koolhidraat in partikelstof word beskryf. Monsters is op glasveselfilters versamel en bewaar deur vriesdroging. Vir proteïen-analise is die gedroogde filter twee keer agtereenvolgens vir 10 minute met 0,1N natriumhidroksied teen 80°C geëkstraheer. Die proteïen is met 10 persent trichloorasynsuur in 'n 1 mg natriumdeoksicholaatmedium neergeslaan. Die neerslag is toe met Folin-Ciocalteureagens laat reageer volgens die metode beskryf deur Lowry *et al.* (1951). Koolhidrate is afgebreek tot suur-oplosbare, alkali-oplosbare en onoplosbare fraksies. Die koolhidraat-inhoud in elke fraksie is bepaal deur middel van die fenol-swawelsuurmetode van Dubois *et al.* (1956). Die totale konsentrasie van koolhidrate is bereken as die som van die drie fraksies. Die akkuraatheid van die metodes en die redes vir die aanpassings gemaak, word bespreek.

In studies of primary production in the Cape Peninsula upwelling region, the physiological response of phytoplankton communities to changes in the environment has been monitored. Analysis of samples to determine their protein and carbohydrate content revealed that the protein: carbohydrate ratio was a useful parameter for monitoring this response, particularly in respect of changes in extracellular nutrient concentration. The extraction of protein was based on the procedure described by Mayzaud and Martin (1975), but a lower concentration of the extracting solution and a shorter extracting time were employed. The precipitation of protein and the colour reaction using the Folin-Ciocalteu phenol reagent follows the method of Bensadoun and Weinstein (1976). However, the final concentration of the precipitating reagents had to be increased twofold to ensure complete precipitation of the protein.

Carbohydrates were fractionated into an acid-soluble fraction (soluble polysaccharides), an alkali-soluble fraction (saccharides of short and medium length) and an insoluble fraction (insoluble polysaccharides) according to the method of Haug *et al.* (1973). Modifications to the length of extracting time and to the determination of total carbohydrate were introduced to adapt the method for samples collected on glass-fibre filters. The carbohydrate content in each fraction was determined by the phenol-sulphuric acid method of Dubois *et al.* (1956).

Details of the methods are described together with a discussion of the reasons for introducing various modifications.

METHODS

The collection of samples at sea was performed by filtering 1-2ℓ of seawater through a 4,7-cm Whatman GF/F glass-fibre filter. Immediately after filtering, the filter was folded, frozen in liquid nitrogen, wrapped in an aluminium jacket (15 mm × 50 mm), labelled, and freeze-dried.

Protein determination

Reagents — 0,1N sodium hydroxide
2% (w/v) sodium deoxycholate
20% (w/v) trichloroacetic acid (TCA)
A = 2% (w/v) sodium carbonate in 0,1N sodium hydroxide
B = 0,5% (w/v) cupric sulphate in 1% (w/v) sodium citrate
C = 1 mℓ of B mixed with 50 mℓ of A just before use
Folin-Ciocalteu reagent — diluted 1:1 with water just before use
Standard — Bovine serum albumin

All reagents were prepared with analytical grade chemicals, BDH Chemicals Ltd.

Procedure — Just prior to the extraction step, the contents of the burette used to measure the volume of the 0,1N sodium hydroxide extracting solution were run back into the reservoir bottle, and the solution was then well mixed. Each dry filter was ultrasonically agitated at 45 kHz for 10 minutes in 10 mℓ of extracting solution before being heated at 80°C for 10 minutes to extract the proteins. After cooling, the filter was centrifuged at 3 800 × g (15°C) for 20 minutes, the supernatant removed and the filter dried by pressing a filter stick, attached to a vacuum line, down onto the filter and sucking dry. The filter was then re-extracted with 10 mℓ of 0,1N sodium hydroxide at 80°C for 10 minutes, cooled and centrifuged. The second supernatant was removed and the filter discarded.

Duplicate 1-mℓ aliquots of both supernatants were diluted to 2 mℓ with distilled water, 0,05 mℓ of sodium deoxycholate was added and, after mixing, the solutions were allowed to stand at room remperature for 15 minutes. To each solution, 2 mℓ of TCA were then added, and the solutions were centrifuged at 3 800 × g (15°C) for 45 minutes. The supernatants were gently removed from the precipitated pellets by suction through a Pasteur pipette attached to a vacuum line. Care was taken not to remove a fine precipitate that collected at the surface.

The precipitated pellets were dissolved in 3 mℓ of reagent C and then reacted with 0,3 mℓ of Folin-Ciocalteu reagent. After mixing, the colour of the reaction mixtures were allowed to develop for 45 minutes in the dark. Absorbances were read against a blank in a 1-cm cuvette at 660 nm using a spectrophotometer. The amount of protein was determined from a calibration curve and total protein was calculated as the sum of the protein content in each extract.

Standard solutions were prepared with 5, 10, 20, 30, 40 and 50 μg of bovine serum albumin per 1 mℓ 0,1N sodium hydroxide, whereas blank solutions contained 1 mℓ of sodium hydroxide only. In preparing calibration curves, standards and blanks were treated with the precipitating and colour reagents as described above.

Carbohydrate determination

Reagents — 0,1N sulphuric acid
29N sulphuric acid
Sulphuric acid, specific gravity 1.84
0,1N sodium hydroxide
5% (w/v) phenol
Standard = D-glucose

All reagents were prepared with analytical gra chemicals, BDH Chemicals Ltd.

Procedure — Each dry filter was ultrasonica agitated at 45 kHz for 10 minutes in 10 mℓ of 0,1 sulphuric acid and allowed to stand at room te perature for four hours. After centrifuging at 3 8 × g (15°C) for 20 minutes, the supernatant w transferred to a clean tube and the filter dried pressing a filter stick (pore size 15-40 μm), attach to a vacuum line, down onto the filter and suckii dry. The filter stick was stored in a saturat solution of sodium tetraborate to prevent cloggi of the porous glass.

The dried filter was resuspended in 10 mℓ 0,1N sodium hydroxide and the mixture allowe to stand at room temperature for a further fo hours. After centrifuging, the supernatant w removed and the filter dried once more.

A volume of 1 mℓ of 29 N sulphuric acid w added to the dry filter, and extraction for insolub carbohydrate allowed to proceed at room temper ture for 20 hours. The mixture was diluted to 5 m with distilled water (in an ice bath), centrifuge and the supernatant removed.

While thoroughly mixing, 1 mℓ of 5-per-ce phenol was added to duplicate 1-mℓ aliquots each supernatant. If required, an appropria dilution was made to bring the concentration carbohydrates into the range of the calibratio curve. Sulphuric acid (5 mℓ) was rapidly added t the centre of the assay solution to ensure a fa exothermic reaction. Caution was exercised i handling the tubes to prevent spillage of the h solutions. After mixing, the solutions were coole and the absorbances read against a blank in a cm cuvette at 490 nm using a spectrophotomete The concentration of carbohydrate in each frac tion was determined from a calibration curve, an total carbohydrate was calculated as the sum c the three fractions.

Standard solutions were prepared with 10, 2 30, 40 and 50 μg of glucose per 1 mℓ of distille water, whereas blank solutions contained 1 mℓ o distilled water only. In preparing calibration curves standards and blanks were treated with pheno and sulphuric acid as described above.

RESULTS AND DISCUSSION

Mayzaud and Martin (1975) and Haug *et al* (1973) collected samples by towing a net horizon tally through the surface layers of coastal waters

ighed portions of freeze-dried particulate matter e then analysed for their protein or carbohydrate tent. In the present study, samples were collected m discrete depths in the water column, and it s therefore more convenient to filter water nples through glass-fibre filters in order to centrate the plankton. This sampling procedure essitated a few changes in the analytical techni-es.

n preliminary tests on the protein method, ious strengths of the extraction solution and erent extractive periods were examined. The sodium hydroxide solution and 30-minute raction time used by Mayzaud and Martin (1975) re found to be unsatisfactory because they gave yields of protein. Extraction in 0,1N sodium droxide at 80°C for 10 minutes gave the best ults for samples with a low protein content. wever, extraction from these low-protein samples longer than 10 minutes gave a lower yield. is may have been the result of protein being de-ded in the alkaline solution during longer raction periods. For samples with high levels of otein, 10 minutes was found to be insufficient to ract all the protein, and longer extraction times d to be employed. To compromise between se extremes, all samples were extracted twice 10 minutes in order to determine the total otein content.

n order to precipitate proteins out of solution, sadoun and Weinstein (1976) used a final TCA centration of 6 per cent for a concentration of µg of sodium deoxycholate per 4 mℓ of reaction ture. In the present study, in standards prepared ,1N sodium hydroxide, it was found that these centrations were too low to precipitate out all protein. Various strengths of the precipitating gents were therefore tested for efficiency of tein precipitation. The addition of 1 mg of ium deoxycholate and 2 mℓ of 20-per-cent TCA 2 mℓ of standard solution was found to give e highest protein recovery. Higher concentrations d not improve the yield of protein.

A wavelength of 750 nm was used to read the sorbances of the assay mixture in the original otein method developed by Lowry *et al.* (1951). is wavelength was optimal for the range 5 — µg of protein. Lowry *et al. (op. cit.)* suggested at, for stronger solutions, absorbance readings uld be kept in a workable range by reading near wavelength of 500 nm. Bensadoun and Weinstein 976) used a wavelength of 660 nm, approximate-midway between 500 and 750 nm, but, because ey gave no specific reasons for using the shorter avelength, it was presumed that 660 nm was selected for a particular range of protein concentrations. Tests made during this study revealed that, at 750 nm, the absorbance readings of standard solutions were ±10 per cent higher than the readings determined at 660 nm. However, the calibration curve prepared at 750 nm was not quite linear, an observation noted by Lowry *et al. (op. cit.)*. Linearity was obtained for curves prepared at 660 nm and it was decided to use this wavelength in the assay procedure.

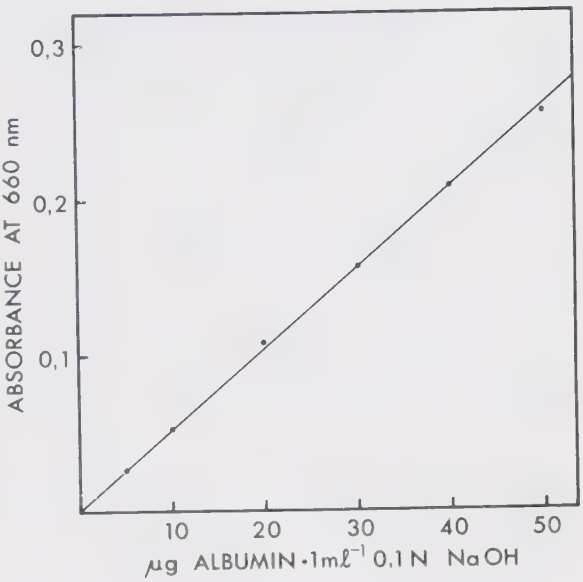

Fig. 1: Calibration curve for protein determination

A calibration curve for protein analysis is given in Figure 1. The method described can be expected to be accurate to within ±4 per cent. This was determined by plotting the results and comparing the amount of protein actually present with that indicated by the plot. The percentage errors are shown in Table I.

In the fractionation of carbohydrates, Haug *et al.* (1973) extracted 20 mg of dry material twice with dilute acid for two hours and then extracted the residue twice with dilute akali for a further two hours. The carbohydrate content of the extracts was then determined. With this technique, it was found in this study that at least 2 mℓ of the acid extract was retained by the glass-fibre filters after centrifugation. This retained portion contaminated the alkali extract. To overcome this, filters were extracted only once with dilute acid or alkali for four hours. The result was the same in terms of

Table I: Accuracy of the protein and carbohydrate methods

Assay	Absorbance	Taken ($\mu g \cdot m\ell^{-1}$)	Found ($\mu g \cdot m\ell^{-1}$)	Error (%)
Protein	0,028	5,0	5,2	4,1
	0,054	10,0	10,3	3,0
	0,108	20,0	20,7	3,5
	0,157	30,0	30,0	0
	0,208	40,0	39,7	0,8
	0,255	50,0	48,8	2,4
Carbohydrate	0,104	10,0	10,2	2,0
	0,205	20,0	20,0	0
	0,307	30,0	30,0	0
	0,405	40,0	39,5	1,2
	0,508	50,0	49,5	1,0

yield of carbohydrate as when they were extracted twice for two hours. It was essential, however, to dry the filters after each extraction step to prevent contamination of the next extract.

Haug *et al.* (1973) determined total carbohydrate by hydrolysing a dry sample with 1 mℓ of 29N sulphuric acid for 20 hours, then diluting the mixture and determining the amount of carbohydrate in the solution. The amount of insoluble carbohydrate was estimated as the difference between total and soluble carbohydrate. Hitchcock (1977) found, however, that the hydrolysis of total particulate matter yielded an underestimate of the carbohydrate concentration. In preliminary tests, a comparison was made of the two methods of carbohydrate determination, i.e. hydrolysis according to the method of Haug *et al.* (1973) and the procedure described here. Higher yields of total carbohydrate were obtained by summation of the carbohydrate content in each fraction than by hydrolysis of the total sample, confirming the findings of Hitchcock *(op. cit.)*. Hydrolysis in strong acid may result in the decomposition of furfural, a compound formed in the assay mixture that produces the colour with phenol.

In order to prepare calibration curves for the carbohydrate determination, standards were dissolved in distilled water, 0,1N sulphuric acid, 0,1N sodium hydroxide and 5,8N sulphuric acid. The last solution was prepared by diluting 29N sulphuric acid five-fold in accordance with the determination of insoluble carbohydrate. The slopes of the curves obtained with these four solutions are shown in Table II, the error differences between the curve with distilled water and the curves prepared with the other solvents being ±2 per cent. This difference was not considered to be enough to warrant preparing three calibration

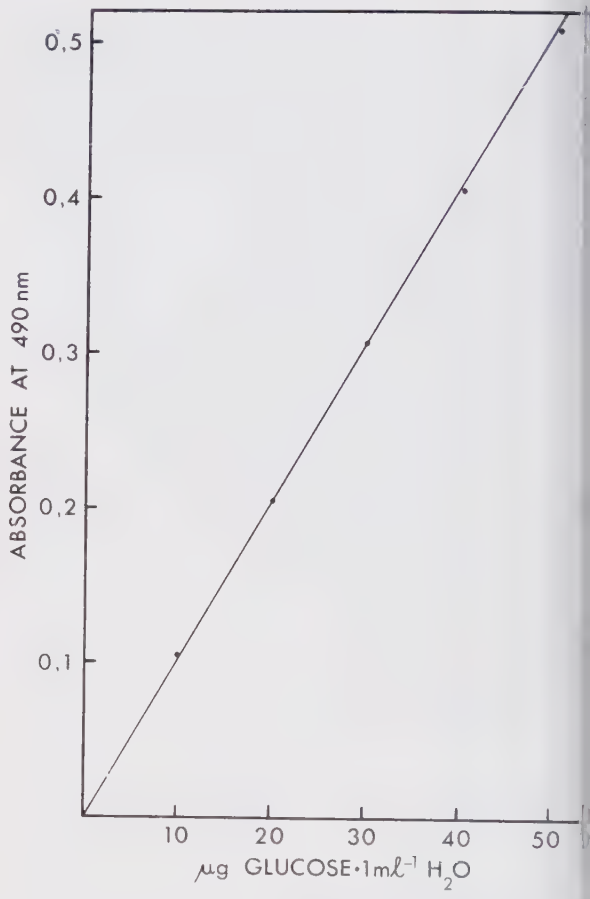

Fig. 2: Calibration curve for carbohydrate determination

curves, and therefore the distilled-water curve was used for determining carbohydrate in all three fractions. It would appear that inorganic substances such as dilute sulphuric acid and sodium hydroxide

Table II: Differences between standard curves for carbohydrate determination

Solvent	Slope of curve	Percentage of error of distilled-water curve relative to other solvents
Distilled water	0,0089	
0,1N sulphuric acid	0,0090	1,1
0,1N sodium hydroxide	0,0088	1,1
5,8N sulphuric acid	0,0091	2,2

e III: Protein and carbohydrate results from samples collected at Oudekraal (10 km south of Cape Town), 1978

ation	Depth (m)	Protein ($\mu g \cdot \ell^{-1}$)	Carbohydrate ($\mu g \cdot \ell^{-1}$)	Protein: Carbohydrate
1	0	172,0	117,7	1,46 : 1
	6,5	151,5	93,2	1,62 : 1
	10	89,0	61,5	1,44 : 1
	16	116,0	60,0	1,93 : 1
	37	93,0	14,5	6,41 : 1
2	0	335,5	1 183,0	0,30 : 1
	2,5	353,0	1 108,5	0,32 : 1
	4	306,5	1 145,6	0,27 : 1
	5	354,5	612,0	0,58 : 1
	9,5	436,0	734,0	0,59 : 1

not interfere with the phenol-sulphuric acid thod of sugar analysis. Similar observations re noted by Handa (1966), when the method s examined for its applicability to estimate solved carbohydrate in seawater.

A calibration curve for carbohydrate analysis is strated in Figure 2. The method can be expected be accurate to within ±2 per cent, which is the curacy recorded by Dubois *et al.* (1956). This ure was calculated in a manner similar to that scribed for the protein method and the percentage ors are shown in Table I.

Some results of protein and carbohydrate de- minations, using the methods described here, are presented in Table III. There is a difference in the concentrations of protein and carbohydrate between the two stations with a resultant difference in the ratio of protein to carbohydrate. Changes in this ratio are being studied as an indicator of the physiological state of natural phytoplankton communities in respect of nutrient availability.

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Bull. S.Afr. 15:95—97

MEASUREMENT OF CARBON-14 ASSIMILATION PATTERNS IN PHYTOPLANKTON

R. G. BARLOW

A method, based on the procedure of Morris *et al.* (1974), is described for determining the assimilation of carbon-14 into the products of photosynthesis. Simulated *in situ* incubations were performed in a deck incubator, and were followed by collection of the phytoplankton on glass-fibre filters and preservation by freeze-drying. Dry samples were then fractionated into an ethanol-soluble fraction (amino acids, monosaccharides, some lipids and pigments), a trichloroacetic acid-soluble fraction (polysaccharides) and a trichloroacetic acid-insoluble fraction (protein). The amount of carbon-14 assimilated into each fraction was monitored on a scintillation counter. Reasons for modifying the original procedure are discussed.

'n Metode, gebaseer op die prosedure van Morris *et al.* (1974), word beskryf vir die bepaling van die assimilasie van koolstof-14 in die produkte van fotosintese. Nagebootste *in situ*-inkubasies is uitgevoer in 'n dek-inkubator en opgevolg deur versameling van die fitoplankton op glasveselfilters en preservering deur middel van vriesdroging. Vir analise is die droë monster afgebreek in 'n etanol-oplosbare fraksie (amino-sure, monosakkariede, sommige lipiede en pigmente), 'n trichloorasynsuur-oplosbare fraksie (polisakkariede) en 'n trichloorasynsuur-onoplosbare fraksie (proteïen). Die hoeveelheid koolstof-14 opgeneem in elke fraksie is gemonitor met behulp van 'n flitsteller. Redes vir die aanpassing van die oorspronklike metode word bespreek.

Steemann-Nielsen (1952) introduced the rbon-14 method of measuring primary productity in the ocean, which has made a significant ntribution to the understanding of the ecology marine phytoplankton. The extent to which it s improved the comprehension of the physiologil state of natural communities is more difficult assess. One reason for this is that the overall e of photosynthesis by phytoplankton can remain proximately constant over wide differences in physiological state of the organisms. A possible y of modifying the carbon-14 method into a chanism indicating the physiological state is to asure the pattern of photosynthesis as well as overall rate.

Morris *et al.* (1974) introduced an appropriate dification by measuring the incorporation of bon-14 into a number of different products ring photosynthesis of a culture of *Phaeodactylum icornutum*. The method involves an extraction phytoplankton samples into ethanol-soluble and anol-insoluble compounds, the latter group being rther separated into compounds soluble and soluble in trichloroacetic acid (TCA). Evidence s presented that carbon-14 incorporated into e TCA-soluble fraction was fixed into polyccharide and that in the TCA-insoluble fraction to protein. The ethanol-soluble fraction would clude metabolites of low molecular weight such s amino acids and monosaccharides as well as me lipids and pigments.

In investigations into primary production conducted in the Cape Peninsula upwelling region, the carbon-14 method has been used to measure the gross production of phytoplankton. Physiological responses of the communities to changing environmental conditions were also monitored, the "modified carbon-14 method" proving useful in these studies. A few modifications to the method of Morris *et al.* (1974) were introduced to adapt it for local field work, and the technique adopted is presented here.

METHODS

Reagents

Sodium bicarbonate-^{14}C (Radiochemical Centre, Amersham)
Absolute ethanol (BDH Chemicals Ltd)
5% (w/v) Trichloroacetic acid — TCA (BDH Chemicals Ltd)

Procedure

A total of 5 mCi of sodium bicarbonate-^{14}C was diluted to an appropriate volume with distilled water (pH 9,0). Aliquots (1 mℓ) of this stock solution, containing 50 μCi sodium bicarbonate-^{14}C, were transferred to glass ampoules in which they were sealed and then sterilized in an autoclave. Neutral-

density bottles were prepared by coating clear glass bottles with varying concentrations of black polyurethane paint in polyurethane varnish. This coating reduced the amount of light penetrating the bottles to the required intensity, as tested with a Biospherical quantum meter.

Replicate 1-ℓ water samples were drawn from appropriate depths in the euphotic zone into the corresponding neutral-density bottles. Simulated *in situ* incubations were performed by spiking each bottle with 50 μCi of sodium bicarbonate-^{14}C, then placing the bottles in a deck incubator flushed with running seawater for four hours. At the end of the incubation period, the contents of each bottle were filtered through a 4,7-cm Whatman GF/F glass-fibre filter, washed with filtered seawater, immediately frozen in liquid nitrogen, wrapped in aluminium foil, labelled, and freeze-dried. The samples were then stored at 5°C until fractionated.

Each dry filter was successively treated with 5 mℓ of cold absolute ethanol for 5-10 minutes and 6 mℓ of boiling ethanol for five minutes. The cooled solution was filtered through a 2,1-cm Whatman GF/C glass-fibre filter and both filters were washed with 3 mℓ of cold ethanol before drying by suction. The combined extracts and washings constituted the ethanol-soluble fraction.

The two filters were treated with 6 mℓ of 5% TCA in a boiling water bath for 30 minutes and, after cooling, the TCA solution was filtered through a 2,1-cm Whatman GF/C glass-fibre filter. The three filters were washed with 5 mℓ of cold 5% TCA and again dried by suction. The combined extracts and washings made up the TCA-soluble fraction, whereas the residue on the filters was designated the TCA-insoluble fraction.

A volume of 2 mℓ of each of the liquid fractions and the three filters containing the residue were assayed for radioactivity in Picofluor-30 scintillation cocktail on a Packard Prias scintillation counter. All counts were converted to disintegrations per minute (DPM) after determining counting efficiency from efficiency correlation curves. Further blank corrections were made for radioactive bicarbonate retained by the glass-fibre filters during filtering. In calculating the proportion of carbon incorporated into each fraction, the total radioactivity was determined as the sum of the three fractions.

In order to prepare efficiency correlation curves, a freeze-dried sample of phytoplankton, not incubated with ^{14}C-bicarbonate, was fractionated into ethanol-soluble, TCA-soluble and TCA-insoluble fractions as described. Aliquots (in triplicate) of the ethanol- and TCA-soluble fractions, ranging in volume from 0,25 to 2,5 mℓ, and triplica TCA-insoluble fractions (extracted filters), we added to 50,1 μℓ of ^{14}C-toluene standard (specif activity of 5×10^4 DPM) in Picofluor-30 scintill tion cocktail and counted. Nine replicate 50,1-μ aliquots of ^{14}C-toluene in scintillation cocktail we counted to determine maximum counting efficienc

RESULTS AND DISCUSSION

Efficiency correlation curves were prepared b plotting the mean count of the triplicate ^{14}C-toluen standard analyses, expressed as a percentage o the activity of the standard, against the externa standard ratio (Fig. 1). The curves for the ethano and TCA-soluble fractions were computed by parabolic least-squares fit and expressed by th following equations:

ethanol-soluble $y = -209{,}9x^2 + 257{,}6x - 11{,}9$

TCA-soluble $y = -248{,}8x^2 + 296{,}2x - 22{,}4$

where y is the percentage efficiency and x is th external standard ratio.

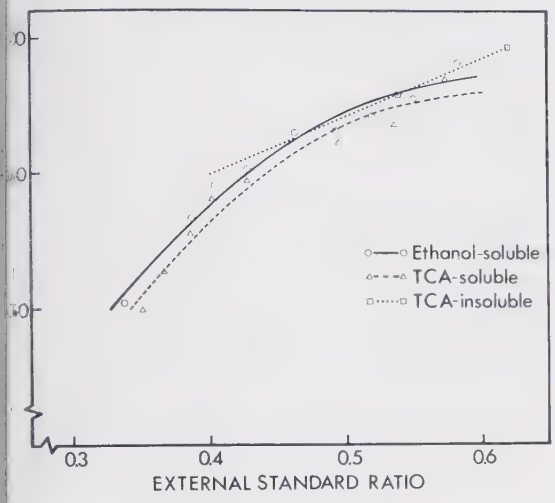
For the TCA-insoluble fraction, it was not poss ble to prepare a range of concentrations becaus the insoluble material remained on the filters Therefore, only the maximum efficiency and th mean efficiency of the triplicate counts on whol fractions could be plotted. The result was a straigh line graph (Fig. 1) expressed by the equation

$$y = 41{,}86x + 43{,}3.$$

The external standard ratios of TCA-insolubl fractions were usually between 0,5 and 0,6, an the graph was considered suitable for calculatin counting efficiencies in this narrow range.

In preliminary experiments to determine th quantity of carbon-14 to be used in incubations samples were spiked with radioactive bicarbonat in a range from 10 μCi to 100 μCi. Incubation wit 100 μCi gave the highest recovered activity, bu 50 μCi gave adequate activities in each fraction and this quantity was used to spike samples in all subsequent experiments. The cost of each experi ment was therefore reduced. Further experiments comparing the total carbon-14 uptake determined by summation of the activities in each fraction with that determined directly, gave recovery values between 93 and 110 per cent.

After filtering, Morris *et al.* (1974) stored their samples in 80-per-cent ethanol at −14°C until they could fractionate the cell constituents. Under



1: Correlation curves for determining counting efficiency in three fractions

al conditions, it was found to be easier to eze and store the filters in liquid nitrogen at and then to freeze-dry the samples in a shore-ed laboratory. Storing the dry samples at 5°C a refrigerator allowed the fractionation to be dertaken at a convenient time several weeks er the samples had been collected.

the method of Morris *et al.* (1974), samples re collected on small filters and, therefore, ll volumes of extracting solvents were used. In present study, larger filters were used because, ly, it was easier to filter through large filters at and, secondly, a greater degree of control d be maintained during freezing of the samples. dangers of liquid nitrogen burns were thus imized. In order to accommodate the larger ers, volumes of the extracting solvents had to increased proportionately.

In order to measure the radioactivity in their fractions, Morris *et al.* (1974) had to evaporate the solutions to dryness before adding their scintillation cocktail. However, the evaporation step may be avoided by using Picofluor-30 cocktail which can absorb as much as 30 per cent by volume of ethanol or TCA. It is also suitable for use with the glass-fibre filters. Counting efficiencies for all fractions varied between 50 and 70 per cent, which was thought to be satisfactory if it is taken into consideration that toluene-^{14}C standards gave a maximum efficiency of 70 per cent with the Picofluor cocktail on the scintillation counter.

A certain amount of radioactivity was absorbed into the glass-fibre filters during the filtration of the water samples and, even though the quantity was reduced by washing with filtered seawater, a correction still had to be made. Filtered seawater, spiked with 50 μCi of bicarbonate-^{14}C, was passed through a Whatman GF/F filter and the blank extracted into the various fractions as described. The background activity for each fraction was then determined.

The assimilation of carbon into the major end-products of phytoplankton photosynthesis is influenced by changes in the marine environment, particularly by light intensity and nutrient availability. The simple and convenient method described in this report may be used to investigate these important physiological responses.

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Bull. S.Afr. 15:99–108

SUGGESTED METHODS FOR OBSERVATION AND MEASUREMENT OF VISIBLE SWARMS OF ANTARCTIC KRILL

I. HAMPTON

Methods are suggested for estimating the size, density and surface dimensions of visible swarms of Antarctic krill *Euphausia superba* Dana. The methods are predominantly visual and rely on a combination of line-intercept and strip-survey techniques. Estimators for the various swarm parameters are discussed and measurement techniques suggested.

Metodes word aan die hand gedoen vir die raming van die grootte, digtheid en oppervlakafmetings van sigbare swerms Antarktiese kril *Euphausia superba* Dana. Die metodes is hoofsaaklik visueel en is gegrond op 'n kombinasie van die tegnieke van siglyninntersep en strookopname. Maniere om die verskillende swermparameters te raam word bespreek en meettegnieke aan die hand gedoen.

here is at present intense international scientiinterest in Antarctic krill *Euphausia superba* a, particularly from the point of view of stock ssment for future resource conservation. A or international krill survey is scheduled for , to be followed by further co-operative surveys ng the rest of the decade. The 1981 survey has n named the First International BIOMASS eriment (FIBEX) and forms the core of the MASS programme guided by the SCAR/SCOR p of Specialists on the Living Resources of Southern Ocean (Anon. 1977).

s a forerunner to FIBEX, the Sea Fisheries ute undertook a krill research cruise in March on M.V. *S.A. Agulhas* (El-Sayed and Hampton). During this cruise, numerous swarms of were seen at or near the surface. Although hip was not equipped for quantitative work isible swarms, because their occurrence in large numbers was not expected, attempts made to quantify them by counting the number in an approximately fixed viewing swath to ide of the survey track. The experience gained suggested a number of quantification methods h could be used in future. The methods are rted here for the benefit of workers on krill ribution, abundance estimation and behaviour.

BACKGROUND

warms of krill occasionally move sufficiently e to the surface to be visible from a ship, and tings have been frequently reported (e.g. Hardy Gunther 1935, Marr 1962, Sasaki *et al.* 1968, moto *et al.* 1979). The swarms are visible as gularly shaped, discoloured patches varying in from a few metres to a few hundred metres across. Very occasionally, exceptionally large patches apparently extending to the horizon have been seen (e.g. Marr 1962 quoting a personal communication by Gunther). Patches are reported as varying in colour from brilliant red to ochre, if right at the surface, to an almost indistinguishable green/brown colour if deeper.

Surface swarming has been reported for both juvenile and adult krill. The conditions under which the krill rise to the surface have not been conclusively determined, although it appears that light intensity is a controlling factor, because swarms have most often been seen at twilight or when the sky has been overcast. They have been observed during particularly inclement sea conditions (El-Sayed and Hampton 1980), showing that a rough sea does not necessarily prevent the swarms from maintaining their integrity close to the surface.

The depth to which the swarms can be seen depends upon factors such as the prevailing viewing conditions, water transparency and the colour of the krill, but there is no doubt that the swarms can only be observed when they are fairly shallow. For example, Cram *et al.* (in press) report an instance where a swarm only 4 m from the surface (deduced by measurements with a helicopter-borne dunking echo-sounder) could not be seen from the helicopter despite the fact that viewing conditions were ideal. It appears that the typical horizontal range at which swarms can be seen is of the order of hundreds of metres.

NEED TO OBSERVE SURFACE SWARMS

Acoustic surveys to assess the distribution and abundance of krill rely almost exclusively on downward-sounding echo-sounders with hull-

mounted transducers. Swarms shallower than about 10 m will not be detected by these sounders, causing a negative bias in the acoustic estimates of abundance. This problem is particularly severe at night, when krill is most likely to be very close to the surface, but the wealth of reports of swarms sighted by day is evidence that the bias is likely to be present to some extent during the day as well. One way of reducing it would be to assess the quantity of krill above the transducer on the basis of measurements on the visible swarms, and then to use this to correct the acoustic estimates. Although not a complete solution to the problem, such an operation would serve to improve the abundance estimates, and from the point of view of delineating krill distribution during the day, would at least ensure that major concentrations are not missed entirely because they are too shallow to detect acoustically.

For example, on a recent South African cruise to the Southern Ocean (El-Sayed and Hampton 1980), numerous swarms were seen over an area of 1 000 square miles centred on 63°S, 4°30′E, but comparatively few swarms were detected acoustically. On one day in particular, 1 570 swarms were counted between 07h30 and 20h00 within a swath approximately 200 m wide, while only 10 swarms, all deeper than 40 m, were detected by the echosounder transducer mounted on the hull 6 m below the surface. Even allowing for differences in effective swath width, it is evident that any acoustic estimate of abundance on this day would have been heavily negatively biased, and that even an acoustic distribution map would have been very misleading.

Observations and measurements on surface swarms would also be useful for improving our understanding of the dynamics of daytime swarm formation and for studying swarm distribution patterns.

PARAMETERS TO BE MEASURED

In order to describe the distribution and behaviour of krill as accurately as possible, and to make the best possible assessment of the biomass contained in visible swarms, it is necessary to take a comprehensive set of measurements and observations on the physical features of these swarms.

It is suggested that either a line-intercept or fixed-swath (strip) survey be set up for this or, preferably, that a combination of the two methods be used. In a line-intercept survey, the sample is restricted to objects intercepted by the survey line, whereas in a fixed-swath survey, the samp consists of all objects seen within a fixed distan perpendicular to the survey line. For krill, t objects are the individual visible swarms.

The line- and swath-survey methods are co plementary; the former is less susceptible to swar being missed because they are too deep indistinct to be observed (swarms passing unc the ship are easier to see than those at a distan to one side), whereas bias arising from swa avoidance of the ship will be less severe in t latter method. The fixed-swath method also h the advantage of providing estimates based or larger sample because of the effectively grea width of the swath. A comparison of the abundan estimates from the two methods should give sor insight into which is the more reliable, and it m also indicate which sources of bias are the mo severe. For example, if the estimate from the li survey was significantly greater than that from t swath survey, it could be concluded that the bi owing to invisibility of swarms was greater th that arising from swarm avoidance of the sh and vice versa.

For simplicity, a rectangular survey area of leng L and width W should be set up. The area shou then be surveyed on a set of transects runni parallel to L and randomly positioned along (i.e. the transects should be of equal length L, b of unequal spacing). For the survey area, ea transect is assumed to give an independent estima of the parameter being measured. Although th survey area could in general be made any shap giving transects of unequal length, certain probler would be introduced, for example, in obtaining a unbiased estimate of number density from th line-intercept method if the distribution is no uniform (Seber 1980). It is therefore recommende that the survey area be kept rectangular. For kr in particular, this is perfectly permissible, becau any area which can be surveyed by a single sh will be very small compared with the overa geographical range of the animal, making the choic of survey area shape to a large extent arbitrary.

In the following sections, details are given o parameters which should be recorded on th surveys. The procedures for making the necessar observations and measurements are suggested i the section on measurement techniques.

Fractional cover

By measuring the length of the intercept fo each swarm intercepted, f, the fraction of th survey area covered by swarms, can be estimate

$$\hat{f} = \frac{1}{kL} \sum_{i=1}^{M} y_i$$

where y_i is the length of the intercept for the i th swarm intercepted, M is the total number of swarms intercepted on all transects and k is the number of transects. The circumflex denotes an estimator. An estimate of the total surface area covered by visible swarms in the survey area is therefore $\hat{f}W$. Abundance can then be determined if the mean swarm thickness and packing density (number or weight of animals per unit volume) can also be estimated.

Seber (1980) shows that, irrespective of the shape of the distribution of the objects, $\hat{f}$ is an unbiased estimator of f. Lucas and Seber (1977) give the following relationship as an unbiased estimator of the variance of $\hat{f}$ for a single line of length L, assuming the objects to be randomly distributed:

$$\text{Var}\,[\hat{f}] = \frac{1}{L^2} \sum_{i=1}^{m} \left(y_i^2 - \frac{\pi}{3W} y_i^3 \right) \quad .$$

where m is the number of objects intercepted on the line.

Naturally the line-intercept method of estimating the fractional cover contains many assumptions, notably that all swarms encountered along the track will be seen, and that the ship does not alter the distribution of the krill in its path. These assumptions may not be totally valid, but at least the method does allow a quantitative assessment to be made.

For the swath survey, the fractional cover can be estimated from the expression:

$$\hat{f} = \rho \bar{s} \quad .$$

where ρ is the number of swarms seen per unit area in the swaths (number density) and $\bar{s}$ is the mean surface area of all swarms seen in the swaths. It is assumed that all swarms in the swath are seen. Alternatively, it would be permissible to replace $\bar{s}$ by $\bar{S}$, where $\bar{S}$ is the mean surface area of swarms in the whole survey area, calculated from measurements made on swarms intercepted on the line-intercept survey. Ways of estimating ρ, $\bar{s}$ and $\bar{S}$ are suggested in the following sections.

Number density

The number density of swarms, ρ, can be assessed from both the line-intercept and the swath surveys. From the line intercepts, ρ could be estimated using McIntyre's (1953) estimator:

$$\hat{\rho} = \frac{2}{kL\pi} \sum_{i=1}^{M} \frac{1}{y_i} \quad (1) \,.$$

Strictly, however, this estimator only applies to circular objects, and it becomes increasingly biased as the objects become more irregular in shape. It is therefore not recommended for krill swarms, which are often very irregular in shape.

The following more general estimator proposed by Eberhardt (1978) would be preferable:

$$\hat{\rho} = \frac{1}{kL} \sum_{i=1}^{M} \frac{1}{w_i} \quad (2) \,.$$

where w_i is the perpendicular distance between tangents drawn parallel to the transect at the right- and left-hand extremities of the i th intercepted swarm (henceforth termed the cross-track width of the swarm). Seber (1980) shows that, for a rectangular survey area, this estimator is unbiased for all shapes of objects and that, for a single transect of length L, it has a variance

$$\text{Var}\,[\hat{\rho}] = \frac{1}{L^2} \sum_{i=1}^{m} \frac{1}{w_i^2} - \frac{\hat{\rho}}{LW}$$

if the objects are randomly distributed.

A comparison between ρ obtained from equations (1) and (2) may give a measure of the non-circularity of the swarms.

In the swath survey, ρ can be estimated from

$$\hat{\rho} = \frac{n}{LD} \quad .$$

where n is the number of swarms counted in the swath of width D. The fundamental assumption here is that all swarms lying within the swath will be seen. This is questionable, particularly towards the extremity of the swath, but at least the sense of the bias is known, so the concentration obtained can be taken as a conservative estimate of the true concentration, which could in itself be useful. It would always be possible to reduce the bias at the expense of variance by reducing the swath width.

Alternatively, if the individual swarms could be ranged, an empirical relationship between swarm visibility and range could be obtained. This relationship could then be used to define an effective survey swath D_e, such that ρ could be estimated from

$$\hat{\rho} = \frac{n'}{LD_e} \quad .$$

where n' is the total of all swarms seen, irrespective of range. This technique is discussed by Eberhardt (1978). The method in principle produces unbiased estimates of ρ, but it is considered unlikely that it will be suitable for assessing the density of visible krill swarms because of the expected difficulty in establishing the range-dependence of swarm visibility (see comments in the Methods section).

Because both the line-intercept and the swath surveys are likely to produce underestimates of , arising from avoidance in the former case and invisibility of swarms in the latter, a comparison between the two estimates could indicate which method is the less biased. This comparison could in turn be useful in isolating the most severe sources of bias.

Swarm size

Sizes (or more properly, the horizontal areas) of individual swarms can be estimated in the course of both the line and the swath surveys.

For the line survey, the intercept y_i gives an estimate of the mean along-track extent of the swarm. A very crude estimate of area can be made from this parameter by assuming the swarm to be circular, making the standard correction for the estimate of the diameter of a circle obtained from a random chord:

$$\hat{s}_i = \frac{4}{\pi} y_i^2 \quad .$$

However, because krill swarms tend to be irregular in shape, it would be better to use a method which takes the actual shape into account. For example, s_i could be estimated from

$$\hat{s} = w_i \, y_i \quad .$$

The variance of this estimate, although still dependent on the irregularity of the swarm, will be lower than that obtained by assuming the swarm to be circular. If real images of swarms can be obtained, for example from photographs, these could be used to assess the magnitudes of the variance for the two methods.

An estimate of $\bar{S}$, the mean size of swarms for the whole survey area, can be obtained from the expression

$$\bar{S} = \frac{\hat{f}}{\hat{\rho}} \quad .$$

In order to assess the distribution of swarm sizes from the distribution of sizes in the swarms intercepted, it is necessary to weight the numbe of swarms intercepted in each size class by th probability of interception, which in this case is

$$\frac{k\bar{w}_j}{W} \quad ,$$

where $\bar{w}_j$ is the mean cross-track width of all inter cepted swarms in size class j. γ_j, the fraction o swarms in the survey area falling into size class j is given by

$$\gamma_j = \frac{N_j}{N} \quad ,$$

where N is the total number of swarms in th survey area and N_j is the total number in size clas j. The expectation value of the total number o intercepted swarms in size class j is given by

$$E[n_j] = kN_j \frac{\bar{w}_j}{W} \quad ,$$

and therefore,

$$\hat{\gamma}_j = \frac{n_j}{k\bar{w}_j L \hat{\rho}} \quad .$$

On the swath survey, swarm sizes can be crudely estimated from measurements of l_i, the along-track extent of each swarm seen in the swath. This method gives the maximum extent of the swarm in the along-track direction, i.e. the diameter if the swarm is circular. Because of the oblique viewing angle, it will not be possible to assess the extent of swarms in the cross-track direction unless they are very close to the ship, and even this could be difficult. The circular swarm assumption will therefore probably have to be invoked to estimate swarm areas during the swath survey. There may, however, be some advantage in at least attempting to assess by eye the ratio of the cross-track to along-track extents of swarms which are sufficiently distinct. Somewhat better estimates of area could probably, therefore, be made.

Unlike in the line-intercept survey, there is in principle no size-dependent bias in the sample. In practice, however, the smaller swarms may well prove to be more difficult to see, leading to an overestimate of the mean size.

In addition to these methods of measuring swarm size, photogrammetric methods could prove useful on occasion. The reliability of these methods will depend largely on the accuracy with which the range to the photographed swarms can be determined.

arm spacing

f it is assumed that the swarms are randomly ributed, the mean and variance of r, the distance ween a swarm and its nearest neighbour, can stimated from expressions developed by Lozow Suomala (1971) for a large number of objects formly distributed in three dimensions. The opriate expressions for the two-dimensional e are

$$\bar{r} = 8\pi\hat{\rho}\int_0^\infty r^2 e^{-4\pi\hat{\rho}r^2}\,dr$$

$$= \frac{1}{4\hat{\rho}^{1/2}}$$

d

$$\text{Var}[r] = 8\pi\hat{\rho}\int_0^\infty r^3 e^{-4\pi\hat{\rho}r^2}\,dr - (\bar{r})^2$$

$$= \frac{0{,}0171}{\hat{\rho}} \quad .$$

As measurements of the spacing between succes- e swarms encountered on either the line or the ath surveys are essentially uni-directional, they not generally be used for assessing r, but could useful for assessing the randomness of the arm distribution (e.g. Pielou 1977).

arm biomass

If measurements of area, thickness and packing sity have been made on a particular swarm, e total biomass contained in it can be estimated. practice, packing density and thickness measure- ents will only be possible on a very small number the swarms seen. The biomass contained in any her swarm would have to be calculated on the sis of the estimated area of the swarm ($\hat{s}_i$), and e thickness and density of the nearest swarm on hich these measurements were made.

warm shape and colour

It would be worth attempting to classify swarm apes, both for studying swarm dynamics and for nproving estimates of swarm size by taking the al shapes of the swarm into account to some extent. Swarm colour is also worth recording as an indication of swarm depth.

Other parameters to be recorded

In order to gain a better understanding of the surface swarming habit in krill, a number of environmental parameters should be recorded at the time that the swarm observations are made. Parameters likely to be relevant are:

- light intensity at the surface;
- vertical profiles of temperature, light and chlorophyll concentration;
- surface temperature;
- water clarity;
- state of sea, wind and ice;
- presence of krill predators;
- vertical and horizontal distribution of phytoplankton species important in the diet of krill;
- stomach contents and state of feeding of captured krill.

These parameters should be recorded both inside and outside a group of swarms to enable comparisons to be made.

MEASUREMENT TECHNIQUES

It is suggested that the various parameters detailed previously should be measured in the manner outlined in the following sections.

Intercepted length of a swarm (y_i)

With the speed and course of the ship constant, the time taken for the swarm to pass a convenient reference mark on the hull should be measured by stopwatch. From the known speed, y_i can be calculated directly.

Number of swarms seen in the survey swath (n)

The primary difficulty in measuring this parameter will be in setting up a fixed viewing swath to the side of the ship. In the absence of ship's roll, a reasonably accurate swath can be obtained from the field of view of an optical device such as a camera, pair of binoculars or a telescopic sight rigidly mounted at a fixed angle (see Fig. 1).

From a knowledge of H, the height of the viewer

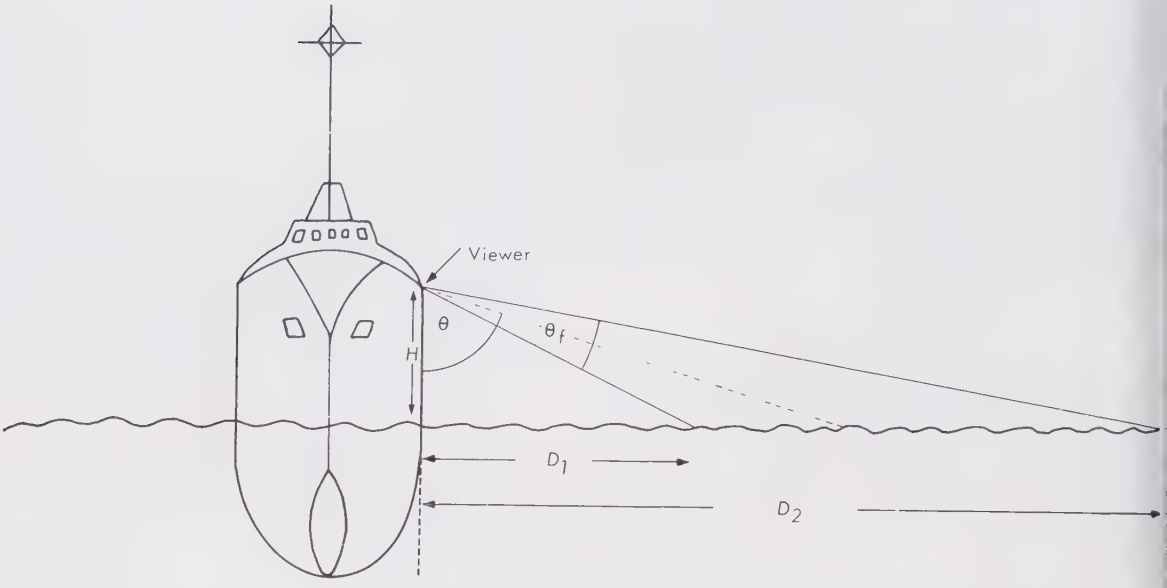


Fig. 1: Oblique viewing to side of ship

above the waterline, and θ_f the field of view, D can be calculated as a function of θ, the inclination of the viewer from the vertical:

$$D = D_2 - D_1 = H\left[\tan\left(\theta + \frac{\theta_f}{2}\right) - \tan\left(\theta - \frac{\theta_f}{2}\right)\right].$$

The assessment technique would then consist of counting all swarms falling either totally or partially into the field of view, making an edge correction for the latter based on the mean width of the swarms. (This type of correction is usual in situations such as this where the width of the objects is, on average, not negligible compared with the swath width.) In practice it would simplify the method to count all swarms lying between the ship and D_2, i.e. to take $D = D_2$. Swarms passing under the ship, but visible on the viewing side, would be counted. Alternatively, a convention could be adopted whereby swarms partly in the swath could be included at one extremity of the swath (preferably the near-side), but not at the other.

The chief failing of this method of fixing the survey swath is that it is very sensitive to ship's roll because of the obliqueness of the viewer. For example, for $H = 15$ m, $\theta_f = 60°$ and $D = 200$ m, a roll of only 5° will cause the viewing swath to swing between 95 m and the horizon. It is doubtful therefore that this method would prove practical

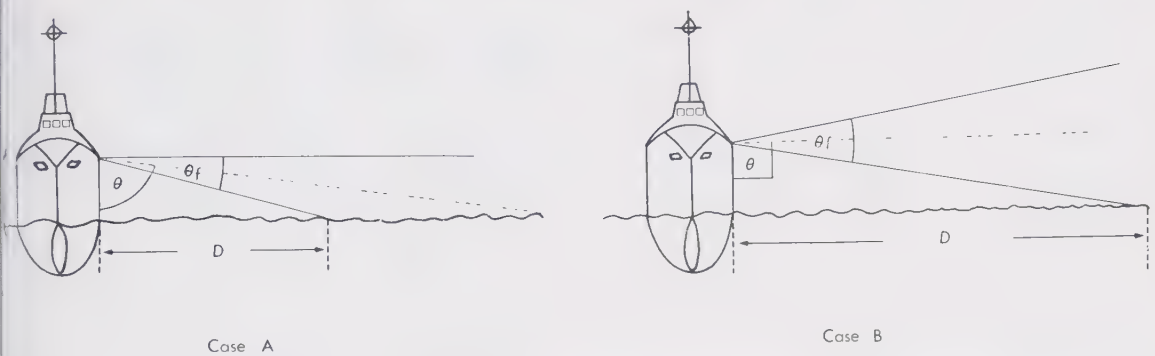
Although it would probably be possible t counteract roll to some extent by gimbal-mountin the viewer, viewing would be rather difficult whe rolling severely. It is suggested that it would b better to compensate manually for roll, using th horizon as a reference, such as is done with sextant. If it is possible to take a sufficiently clea sextant sight on the swarm, θ_h, the vertical angl between the swarm and the horizon can be rea off directly, allowing D to be determined from knowledge of H:

$$D = H \cot(\theta_h + \theta_H) \quad ,$$

where θ_H is the dip angle of the horizon. Fo $H = 15$ m, $\theta_H = 7'$ in the absence of refraction and for the accuracy sought in this measurement can be ignored. Therefore, D can be estimate from

$$D = H \cot \theta_h \quad .$$

The most practical way to utilize this technique would be to set the sextant for a chosen value o D, and then to include or exclude each swarm according to whether its image appeared below o above the image of the horizon. This method o setting up the survey swath would be both simple to use and relatively accurate. There is, however



g. 2: Viewing with viewer trained on horizon — (A) horizon at top of frame, (B) horizon across centre of frame

ne doubt as to whether images of swarms ained through a sextant will be sufficiently ble to use the method, and for this reason the owing alternative is proposed.

f a viewer with a known field of view is held so t the horizon appears either at the top (Case A) across the centre (Case B) of the viewing frame, range of objects appearing at the bottom of frame can be calculated (see Fig. 2). By manually ing the viewer to keep the horizon steady as the rolls, it should be possible to keep θ and ce D approximately constant. It is assumed : H remains constant, which is not strictly true ause H changes with pitch, roll and swell, but is likely to have only a second order effect on The method would then consist of taking all rms which can be seen in the viewer as being side the survey swath. Swarms partly outside swath should be counted and the swath correct- or this effect as explained previously.

n order to obtain a useful swath, the field of w would have to be narrow. Figure 3 gives D as unction of θ_f for Cases A and B of Figure 2, ng H as 15 m. For a different height H', the ath width D' can be calculated from

$$D' = \frac{DH'}{15}$$

gure 3 shows that, for θ_f more than about 9° in ase A and 18° in Case B, the survey swath comes too narrow to be useful (D <100 m). deally, a viewer with a field of view adjustable to e prevailing viewing conditions should be used. rom this aspect a telescopic sight of variable agnification or a camera with a zoom lens would robably be the most suitable viewers. Alternative- , a camera with a suitable series of fixed lenses a suitable set of fixed telescopic sights or binoculars would also suffice. To assist in choosing a viewer, typical viewing angles for a number of optical devices are given in Table I together with the corresponding values of D for H = 15 m.

Whatever viewer is used, it is advisable to check the nominal field of view by observation of a graduated scale at a known distance from the viewer. If manually compensating for ship's roll, it would be necessary to mount the viewer in such a way that it could easily be tilted on its mounting. It will also be found helpful to fit the viewer with a polarising filter to reduce glare from the surface and so to enhance the visibility of the swarms.

The swath width should be established by choosing a distant swarm which is clearly visible and adjusting the field of view so that, with the horizon across the top or the centre of the viewing frame, the edge of the swarm just appears in the bottom of the frame. If selecting a viewer from a number of devices with fixed viewing angles, that which most nearly brings the swarm into line with

Table I: Typical viewing angles and swath widths (for H = 15 m) for various optical devices

Device	θ_f (degrees)	D (m) Case A	D (m) Case B
28 mm wide-angle lens	75	7	19
35 mm wide-angle lens	62	8	25
50 mm standard lens	46	14	35
100 mm telephoto lens	24,5	33	69
135 mm telephoto lens	18	46	94
200 mm telephoto lens	12	70	142
400 mm telephoto lens	6	142	286
80-200 mm zoom lens	30-12	26-70	55-142
5 × binoculars	5	171	343
10 × binoculars	2,5	343	690
2-6 × telescopic sight	1-4	70-214	55-429

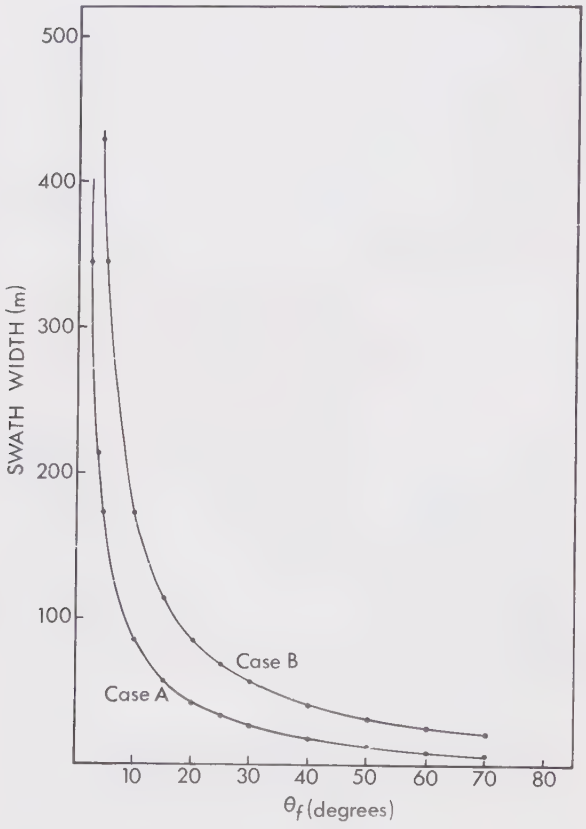


Fig. 3: Swath width as a function of θ_f cases A and B (H = 15 m)

the bottom of the frame should be selected. The procedure should be repeated on a number of different swarms in order to establish a more broadly based viewing swath.

A further method worth trying would be to use a range-finder to measure the range of each swarm, and then to include or exclude it according to whether it falls inside or outside the defined viewing swath. Split-image optical range-finders which have a resolution of better than 5 per cent at 1 km are available, but to work effectively they require that the object be clearly visible and easy to bring into focus. It is doubtful whether krill swarms will often present suitable targets for this method, because they are usually difficult to see even with the naked eye and the images are difficult to bring into coincidence because of the lack of surrounding contrast. Nonetheless, under good viewing conditions a range-finder could be useful, either for conducting the assessment itself, or for checking on the width of the survey swath set up by anoth method. It is worth noting that the range-find method may be the best in bad weather when th rolling of the ship makes it difficult to use a fiel of-view method. The range-finder will not be undu affected by ship's roll, and the sharp contrast breaking waves in the vicinity of the swarm cou be used to focus the instrument.

It is difficult to predict which of these metho would be best for establishing the viewing swat It would probably prove worthwhile to be equippe for them all, and then to establish from experienc which is the more accurate and easy to use und a particular set of circumstances.

Once the survey swath has been establishe the assessment method would consist simply counting the number of swarms seen for a know length of transect.

Cross-track width of a swarm (w_i)

This cross-track width of a swarm can be assesse with a viewer trained on the bow (see Fig. 4 Because the height of the bow and its distanc from the viewer can be measured, the distance t the swarm as it enters the line of sight of the bo can be determined from the expression

$$R = \frac{HR_B}{H - H_B}$$

R therefore depends only on the ship and th position of the viewer. Once R is known, w_i ca easily be obtained, for example by taking a sextan or compass bearing on the port and starboar edges of the swarm as it enters the line of sight o the bow.

Along-track extent of a swarm (l_i)

The along-track extent of a swarm passing t one side of the ship can be obtained by measurin with a stopwatch the time taken for the swarm t pass a fixed point in the viewing frame an multiplying by the ship's speed.

Swarm depth and thickness

In good weather it should be possible to use an acoustic transducer towed on the surface to measure the depth and thickness of swarms passing close to the ship, particularly when steaming slowly, for

Fig. 4: Assessment of the cross-track width of a swarm

nple when towing nets. The transducer should owed from a point near the bow so that the surement is taken on swarms relatively un- rbed by the ship. For a high-resolution sounder se length less than 0,5 ms), it should be possible etect swarms to within 1 m of the transducer, the transducer is towed 1 m deep, swarms oer than 2 m should be detectable. In bad ther or at higher towing speeds, turbulence aeration near the transducer will increase the imum range at which the swarms can be de- ed, probably to the extent that the towed sducer will not be useful.

rm packing density (number/weight per unit ne)

imed surface-towed nets, streamed from the from as far forward as possible, should be to estimate the packing density of swarms. It id be possible to see the net passing through swarm, allowing the actual fishing time to be sured by stopwatch. Together with the weight e catch and an estimate of the volume filtered e net during this time, an estimate of swarm ing density can be made.

rm shape

he shape of swarms close to the ship can be ermined photographically or by sketching, vided that they are distinct enough for the ndaries to be discerned. When photographing rms, it is recommended that a polarizing filter used to reduce the effects of surface glare. ause the swarms are often seen in poor light, a lens and a high-speed colour-reversal film) ASA or better) is recommended. It is possible t a red filter would enhance the contrast of the swarms against the sea, but the resulting loss of light may well offset any advantage gained. This postulate would have to be established by experiment. It would also be worth experimenting with other films, particularly with infra-red and polaroid film. If using infra-red film (colour or monochrome), an appropriate blocking filter would have to be used.

In addition to the above it would probably also be worth attempting to characterize the shapes visually according to the classification in Table II.

A combination of classifications might be necessary to characterize a swarm; for example, a crescent-shaped swarm with open water inside it should be given the classification 3,4.

Swarm colour

Apart from using colour photography, it should

Table II: Swarm shape classifications

Classification	Type	Notes
1	Elliptical	Regular circle or ellipse. Specify ellipticity (ratio of major to minor axis) and direction of major axis relative to ship's head.
2	Ribbon-shaped (streamer)	Width in one direction at least 10 times greater than at right angles to it. Specify direction of long axis relative to ship's head.
3	Crescent	Specify direction crescent points relative to ship's head.
4	Annular or "open"	Clear water within outer boundary of swarm.
5	Amorphous or "amoeboid"	Shape too irregular to fit any of the above categories.
6	Extensive	Swarm too large to be able to discern shape.

Table III: Colour classification scheme of swarms

Code	Colour
1	Bright red
2	Dull red
3	Bright orange
4	Dull orange or ochre
5	Brown
6	Green/brown — almost indistinguishable

prove useful to classify the colour of swarms according to Table III.

If necessary a combination of these codes could be used. In time it might be possible to draw up a colour comparator chart to make colour classification less subjective.

CONCLUSION

It is felt that the application of some, if not all, of these methods should assist in placing the observation of visible krill swarms on a more objective footing than has been achieved to date. It should be emphasized, however, that the methods have yet to be evaluated. By encouraging their general use, it is hoped that the methods will be thoroughly evaluated for a wide range of swarming behaviour and viewing conditions, so that their general applicability can be assessed.

ACKNOWLEDGEMENTS

I wish to thank Dr D. S. Butterworth, Department of Applied Mathematics, University of Cape Town, for reviewing the manuscript and acquainting me with certain line-intercept and strip-survey techniques. Messrs J. J. Agenbag and D. G. M. Miller are also acknowledged for their helpful comme on the manuscript.

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RECENT OBSERVATIONS AND SOME HISTORICAL RECORDS OF SOUTHERN RIGHT-WHALE DOLPHINS *LISSODELPHIS PERONII*

*R. A. CRUICKSHANK and S. G. BROWN**

Seven sightings of the southern right-whale dolphin *Lissodelphis peronii* in the Benguela Current system off South West Africa and one sighting off Marion Island in the southern Indian Ocean are reported together with some unpublished historical records. The occurrence of the species in the South-East Atlantic is confirmed and discussed in relation to documented records and some relevant museum calvaria of the species. Some colour variations are reported. Swimming behaviour and speeds, herd configurations and sizes, and reactions to other species and ships are noted. Sea surface temperatures were between 5,2°C and 20,1°C, both of which limits lie outside the previously reported temperature range for the species. A circumpolar distribution within the cold waters of the subtropical zone of the southern hemisphere is demonstrated. The feasibility of applying information on colour variants to studies on behaviour and social grouping is assessed.

Verslag word gedoen van sewe waarnemings van die suidelike noordkaperdolfyn *Lissodelphis peronii* in die Benguela-stroomstelsel langs die kus van Suidwes-Afrika en een waarneming by Marion-eiland in die suidelike Indiese Oseaan asook enkele ongepubliseerde historiese gevalle. Die voorkoms van die spesie in die Suidoos-Atlantiese Oseaan word bevestig en bespreek met betrekking tot gedokumenteerde gevalle en 'n paar tersaaklike skedels van die spesie in museums. 'n Paar kleurvariasies is waargeneem. Swemgedrag en swemsnelhede, tropkonfigurasies en -groottes, reaksies op ander spesies en skepe word aangeteken. See-oppervlaktemperature was tussen 5,2°C en 20,1°C, en albei perke lê buite die voorheen genoteerde temperatuurbestek vir die spesie. 'n Sirkumpolêre verspreiding binne die koue waters van die subtropiese sone in die suidelike halfrond word gedemonstreer. Die moontlikheid om inligting oor kleurvariante aan te wend in studies van gedrag en sosiale groepering word getakseer.

The southern right-whale dolphin *Lissodelphis peronii* and the northern species *L. borealis* are named to be so named because of their characteristic lack of a dorsal fin (Gaskin 1972). Generally they are considered to be cool-water species (Gaskin 1968 and *op. cit.*, Brown 1973, Leatherwood and Walker 1979). *L. peronii* reportedly occurs in the southern hemisphere, primarily between the Subtropical and Antarctic Convergences, but it also extends further north in such cold water regions as the Humboldt Current. It has been recorded between 58°S and 64°S off Cape Horn (Fraser 1955, Brown *op. cit.*, Brownell 1974). All observations published to date are contained between longitudes 110°E and 45°W — except one each at 20°E, at 8°E and at 7°W — and between latitudes 32°35′S and 65°S (Fraser *op. cit.*, Gaskin *op. cit.*, Brownell *op. cit.*), apart from one record at 18°53′S off the Humboldt Current (Brown *op. cit.*). Therefore, all but two of the published records are from South-West Atlantic, South Pacific and Australian waters.

The nearest positive record of southern right-whale dolphins to southern Africa was a sighting made in 1926 at 38°34′S, 8°06′E (Fraser 1955) which led Barnard (1954) to suggest that the species might occur off southern Africa. On the basis of surface temperatures related to dolphin distribution, Brown (1973) further suggested that the species might be found in the waters of the cold Benguela Current off South West Africa. There are three skulls confirmed to be of the species, but with doubtful origins, now in museum collections in Europe. At least two of these were probably collected from South African beaches in the nineteenth century:

1) a calvarium in the Zoology Museum, University of Amsterdam (ZMA 11.808) presented by Max Weber, 1894/95, without data, but which was most probably found on a South African beach (P. J. H. van Bree, *in litt.* to P. B. Best 24.9.70);

2) a skull in the Muséum d'Histoire Naturelle, Lab. d'Anatomie comparée, Paris (MNHN-B.2/89) No. 2, collected by M. Dussumier in 1822 from "du Cap" (P. J. H. van Bree, *in litt.* to G. J. B. Ross 8.12.75). Van Bree (*in litt.* to R. A. Cruickshank 5.12.79) points out that the intact animal from which the specimen comes is shown in a drawing by Dussumier (Arvy 1972).

The Muséum d'Histoire Naturelle also has a skull (MNHN-1928.195) No. 5, collected at Baie de la Conception. This specimen could have originated from Conception Bay, South West Africa (23° 55′S, 14°30′E) or, less likely, from Point Conception,

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California (34°21'N, 120°40'W). However, considering the prominence of Talcahuano, Concepción, Chile (36°50'S, 73°03'W) as a settlement during the last century, it is perhaps more likely that the skull was collected there.

There are four skulls in the Rijksmuseum van Natuurlijke Historie at Leiden which are labelled *Prodelphinus peronii* (Jentink 1887). Schlegel (1841) described one of these as *L. peronii* and stated that it originated from the Cape of Good Hope, but True (1889) believed it to most resemble *Prodelphinus froenatus*. Van Bree (*in litt.* to R. A. Cruickshank, 5.12.79) agrees with True that all four specimens are *Stenella* sp.

From 1926 to 1978 no further records of *L. peronii* off southern Africa were reported. This account presents details and photographs from seven sightings off South West Africa between 1978 and 1980 and from one at the Prince Edward Islands in 1980.

PRESENT SIGHTINGS

In consecutive months, from October to April 1978/79 and 1979/80, the Sea Fisheries Institute R. S. *Benguela* made monthly ichthyoplankton and hydroacoustic surveys. These extensive surveys covered the whole coast between the Cunene and Orange Rivers, but the major effort was 26 east-west survey lines between the Cunene River (17°40'S) and Lüderitz (26°40'S) extending 65 nautical miles off shore.

During four of the eleven survey cruises, southern right-whale dolphins were sighted, all between latitudes 26° and 26°40'S and longitudes 13°45' and 14°49'E (Table I and Fig. 1). In April 1980, a further sighting was made slightly south of that area (H. Walters, Sea Fisheries Institute, personal communication). Four other research cruises completed in the same area during the winters of 1979 and 1980 resulted in no sightings of *L. peronii*.

One winter sighting was made from the M.V. *S.A. Agulhas* between Marion and Prince Edward Islands in the South-West Indian Ocean during a hydroacoustic and plankton trawling survey.

DESCRIPTION OF THE ANIMALS

The very distinctive markings and the absence of a dorsal fin render this dolphin species unmistakable at sea. Female specimens up to 2 m long and males up to 2,5 m long have been measured (Philippi 1893, Gaskin 1972, Brownell 1974). They have a sharply divided colour pattern: black dorsally and white ventrally. The white is more extensive and obvious in *L. peronii* than Leatherwood and Walker (1979) found in *L. borealis*. The rostrum, anterior portion of the melon, flanks and dorsal surface of the flippers in *L. peronii* are white. In both species the dorsal surface of the tail flukes is dark grey paling to a white leading edge.

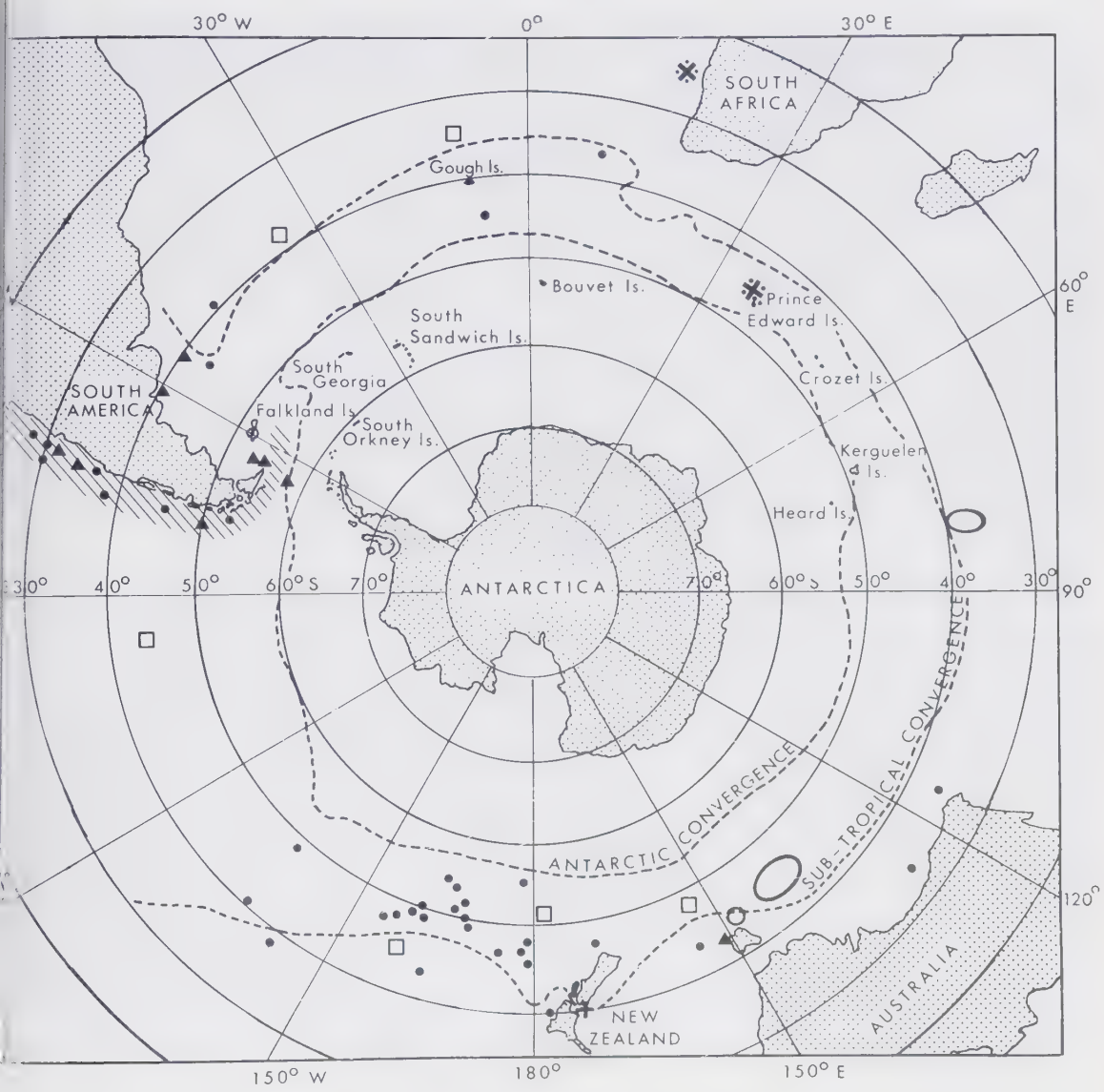
Minor but interesting colour variations were noted in separate herds.

(i) A white dorsal patch on the melon was observed on some of the animals seen in December 1978. The position of this white spot was consistent, but it varied in size (Fig. 3).

(ii) Two of the animals seen in January 1979 had the white of their flanks uniting dorsally, giving the appearance of a saddle over the back (Fig. 7). Brown (1973) noted one animal in a herd of 20 in the mid-Pacific which was completely white. Brownell (1974) and Leatherwood and Walker (1979) refer to eight colour

Table I: New sightings of the southern right-whale dolphin *Lissodelphis peronii*

Date	Position		Estimated number of animals	Other species present	Estimated number of other species	Age classes	Sea surface temperature (°C)
13.12.78	26°40'S	14°14'E	40-50	*Lagenorhynchus obscurus*	50-60	Adults	16,2
23.1.79	26°00'S	13°45,9'E	3	*Globicephala* sp.	20	Adults	17,5
24. 1.79	26°20'S	14°04'E	6	*Lagenorhynchus obscurus*	14	Adults	17,0
24. 1.79	26°40'S	14°49'E	200-300	—	—	Adults + Juveniles	20,1
18. 2.79	26°40'S	14°35'E	15-20	—	—	Adults	17,0
1. 4.80	26°06,2'S	13°57,5'E	15	—	—	Adults	15,7
19. 4.80	27°15,9'S	14°18,1'E	15	—	-	Adults	16,7
28. 5.80	46°50,8'S	38°02,1'E	150	*Globicephala* sp.	20	Adults	5,2



1 Distribution of *L. peronii* sightings in the southern hemisphere, including recent sightings reported in text (after Fraser 1955, Brownell 1974)

Fig. 2: Southern right-whale dolphins *Lissodelphis peronii* (photo. P. E. Malan)

variants of *L. borealis* from Japan and California which were remarkably consistent in having a white blaze on the lateral aspect of the rostrum and melon. One of these animals was quoted from Tobayama, Uchida and Nishiwaki (1968) who had originally described it as a specimen of *L. peronii.*

(iii) A variation in the amount of black on the upper surface of the flippers has been observed. In some animals this consists simply of a edge of black on the posterior margin of th flippers. In others, the pigmented edge i limited to either the mid-region or to th insertion of the flipper on the body. Certai specimens may have only a spot, others hav a large black patch and still others (as far a could be seen) have plain white flippers (Figs 2, 3 and 4). Fraser (1955) gives some evidenc of variation in flipper colouration in thre

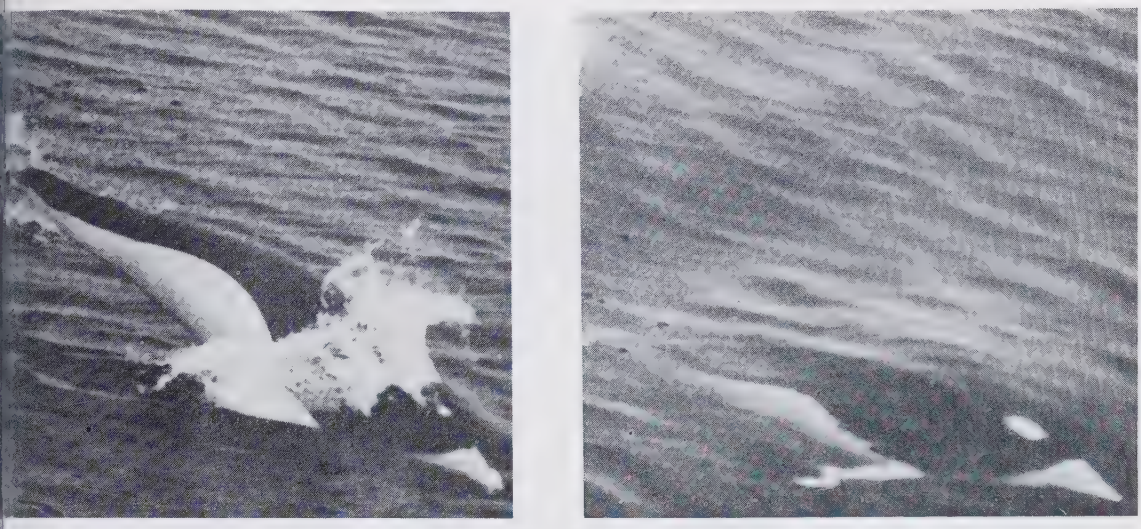


Fig. 3: *L. peronii* with colour variation — white spot on melon (photo. R.A.C.)

4: *L. peronii* with colour variation — black patch on posterior edge of flipper (photo. P. E. Malan)

dolphins stranded at Golden Bay, New Zealand. Bennet (1840), D'Orbigny and Gervais (1847) and Philippi (1893) detail similar variations of this character. Aguayo (1975) describes a female caught off the coast of Chile which had grey pigmentation on the flippers, more extensive on the right flipper than on the left. More evidence of variation in flipper colouration was given by Torres and Aguayo (1979), who reported a black posterior edging on the upper surface of the flippers of a specimen caught off central Chile.

A variation in the colouration of the flukes was reported by Fraser (1955), who recorded a varying amount of black on the posterior ventral surface and grey-blue to wholly black on the dorsal surface. Fraser *(op. cit.)* also quotes Lillie (1915) who described the tail flukes as wholly white above and below. D'Orbigny and Gervais (1847) and Philippi (1893) describe the tail flukes as wholly black on the dorsal surface. Colour variation of the tail flukes was not observed in the present sightings.

Juveniles had identical colour patterns to those of the adults, but some (smaller) calves appeared to be grey dorsally when submerged. Pale coloured calves have been reported for *L. borealis* (Leatherwood and Walker 1979).

BEHAVIOUR

Swimming strategies

Descriptions of swimming behaviour of *L. borealis* by Leatherwood and Walker (1979) are consistent with those recently observed for *L. peronii.* They

Fig. 5: Slow moving *L. peronii* together with dusky dolphins (photo. R.A.C.)

may be summarized as follows:

1. slow moving, exposing just head and blo hole to breathe (Fig. 5);
2. (a) rapid swimming just below surface, surfac briefly to breathe, then resubmerging;
   (b) fast, surface swimming with much leapi (Figs. 6 and 8) making a series of lo angled jumps, either re-entering the wa smoothly head first, or,
   (c) belly-flop and side-slap or lobtail on entering thus causing obvious surface dist bance (Fig. 7);
   d) sounding (10 — 75 seconds individually a up to six and a half minutes for a herd);
   (e) bow-riding.

In the present sightings, bow-riding was acco panied by frequent leaping immediately behi the bow wave. High-speed leaping with lobtaili when performed by a large group, gives the i

Fig. 6: Fast moving, high leaping *L. peronii* (photo. P. E. Malan)

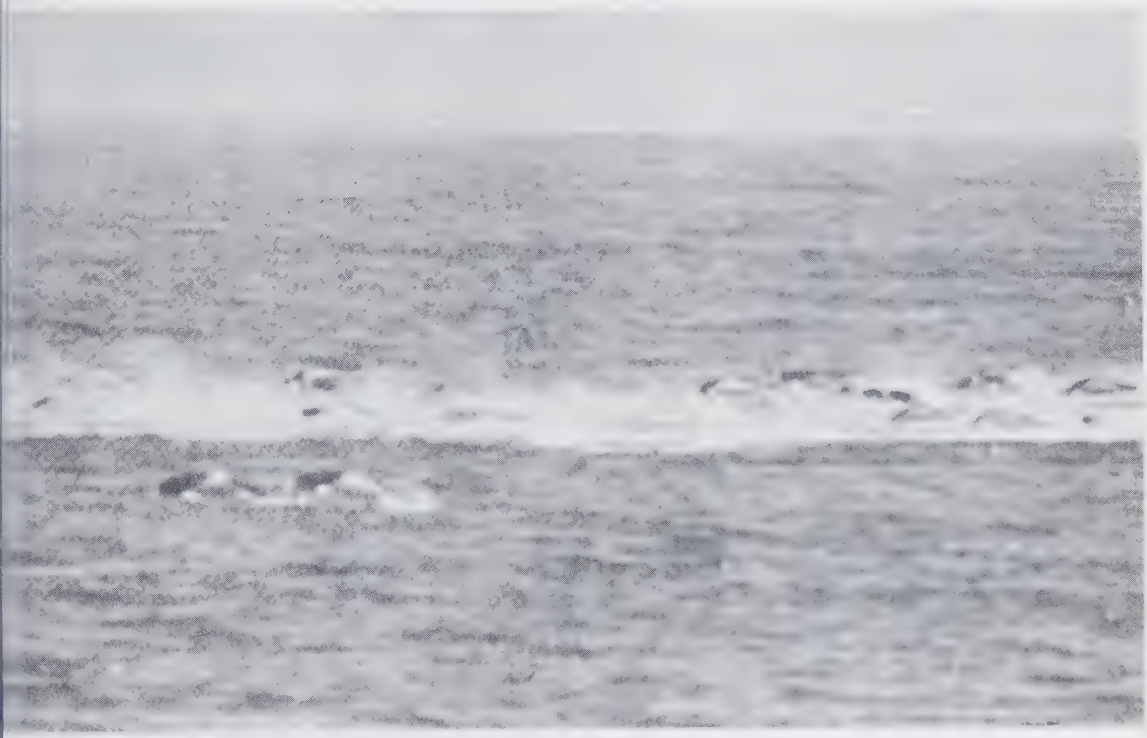


Fig. 1: Fast moving *L. peronii* — note colour variant in foreground with white on flanks extending over back to form saddle (photo. P. E. Malan)

ssion of a series of bouncing leaps which may n stained for a considerable distance.

hen observed in dense herds the dolphins engaged in activities (1) and 2 (d), but some als also made low-angled leaps and occasional leaps within the confines of their tightly packed e. Two small groups of right-whale dolphins, group observed with pilot whales and one dusky dolphins in January 1979 (Table I), rmed a slow version of activity 2 (b) but, in company of the dusky dolphins, also made ral low-angled leaps.

he largest group sighted was accompanied by other species. The animals stayed in a tight le displaying swimming modes (1) and 2(d). y mildly disturbed initially, the whole group denly exploded into action so that individuals, ps and subgroups could be distinguished. A subgroups sounded, then emerged alongside rode or chased behind the bow-wave. The fled from the ship's path in activity 2(a), but n changed to 2(b) with increasing frequency of ping among the herd. The forerunners of this up then changed to activity 2(c).

As the swimming methods changed in tempo so also did the speed. Finally, at very high tempo and speed (causing an impressive spray crest on the calm sea), the animals gave the impression of hardly re-entering the water, but appeared to bounce themselves with a well-timed flick of their tails as they broke the surface. They maintained this method of swimming for 5 — 6 miles so that their progress could be monitored by means of the spray crest for half an hour.

Twice in April 1980 a small pod approached the vessel while it was stationary and milled around the bow. When the vessel steamed on again, the dolphins rode the bow-wave at speeds of 2 — 12 knots, then veered off and followed for up to 20 minutes at positions 20 - 40 m abeam of the ship.

Swimming speeds

Philippi (1893) reported that *L. peronii* has been sighted frequently ". . . swimming at extraordinary speed." In the present sightings, the animals also showed that they are capable of high speeds.

They either chased beside the vessel or rode the bow-wave for up to 20 minutes at sustained speeds of up to 12 knots. Some animals dropped back, perhaps to rejoin the herd, but then chased after the ship again and continued as before.

Leatherwood and Walker (1979) quote estimated speeds for *L. borealis* of 17 — 19 knots (32 — 35 km/h) from other sources, but also present accurately measured speeds of 15 knots sustained for 26 minutes and more than 18 knots for 10 minutes. No speed measurements of *L. peronii* are recorded in the literature.

Herd configurations

Herd configurations observed conform to those of *L. borealis,* as described and illustrated by Leatherwood and Walker (1979). The configurations observed as related to the swimming activities adopted are recorded here for the December 1978 sighting and for the large herd sighted on 24 January 1979. On both occasions the dolphins were found in schools conforming roughly to type I of Leatherwood and Walker *(op. cit.),* their main feature being the dense packing and the lack of identifiable subgroups. In these instances the schools as units were static, but individual animals were swimming about slowly within the circular units.

Different configurations were observed in reaction to the ship's approach. In December the type I grouping broke open into type II groups, then reformed the dense type I grouping to remain circling in approximately the same place.

In January, the herd moved off keeping type I configuration, then broke into several groups of type II. In this formation, subgroups (2 — 5 animals) and clusters of subgroups were distinct (Fig. 8). In these configurations various methods of swimming were evident. However, as the method of swimming changed so also did the herd grouping. The general herd (those fleeing from the path of the ship) split into a high-speed group ahead and a fast-moving cluster of subgroups including those with calves. The front group quickly formed the spearhead V-configuration of type III and displayed swimming activity 2(b) with continual rapid leaping, while the rest swam close behind in activities 2(a) and 2(b), with less spectacular leaping and grouped more or less as in type II. This second group later increased the tempo of their swimming and leaping to join the frontrunners. The whole herd then spread out in the type IV "chorus line" formation approximately 400 m wide. They maintained this formation and activity until they were out of sight, which was approximately eight miles from where they originally made their appearance.

The group riding the bow-wave remained wi the ship for 5 — 6 miles; then each subgroup turn broke away to rejoin the herd. The last t subgroups turned away when they were mo than five miles from the herd, but they unerring headed off in the right direction and sound after brief subsurface swimming.

Herd sizes

The number of animals at each sighting vari from 3 to between 200 and 300 (Table I). Howeve the first three sightings were of schools mix with other species and the actual herd size of t mixed group was consequently larger. Four of t sightings were pure schools of *L. peronii* wi 15 — 300 individuals in each. These fit in t range for sightings of between 1 and over 1 0 individuals of *L. peronii* and up to 2 000 *L. borea* reported in the literature (Gaskin 1968 and 197 Brown 1973, Brownell 1974, Leatherwood a Walker 1979).

Interspecific associations

Individuals of *L. peronii* have been previous recorded with other cetacean species (Brown 1974), and Fraser (1955) has (tentatively) identifi *Lagenorhynchus obscurus* as associating with the Four of the eight sightings documented here we with other dolphin species. On two occasions th were observed with dusky dolphins *Lagenorhynch obscurus* and twice with pilot whales *Globicepha* sp.

Leatherwood and Walker (1979) list *L. borea* as having been sighted with 12 other cetace species in positive association. *Lagenorhynch obliquidens* and *Globicephala* spp. were respectiv ly the first and third most common associates *L. borealis.* It would seem, therefore, that t southern and northern species of *Lissodelph* associate most frequently with the closely relat southern and northern counterparts of the *Lagen rhynchus* and *Globicephala* genera.

Reaction to ships

During the eight sightings, *L. peronii* did n display a consistent reaction to the close approa of a ship, and the reaction did not appear depende on the presence of other species. On two occasio pure *L. peronii* herds showed fear or great excit

8· Large herd of *L. peronii* showing different swimming activities and distinct subgroups (photo P E Malan)

t. Twice (in one month) the animals were
aid and calm alongside the stationary or
ing vessel. On three occasions, once with pilot
les and twice with dusky dolphins, they
layed indifference or mild agitation. In May,
n a herd was sighted at Marion Island with a
rrate herd of pilot whales in the vicinity, the
t-whale dolphins fled suddenly. It was not
r whether their agitation was caused by the
roach of the ship or by the pilot whales.

eniles

n seven of the eight sightings, only adults were
inguished, but on 24 January 1979 at least 10
eniles were distinguished by size or by their paler grey dorsal appearance when submerged. These calves kept close to an adult (mother?) and behaved in the same way as the adults. This agrees with Gaskin's (1972) findings for "half-grown animals".

ENVIRONMENTAL DATA

Physical

Sea surface temperatures at the sightings off South West Africa, according to thermosalinograph records at the time, ranged from 15,7 to 20,1°C (mean 17,2°C). The highest temperature is 1,8°C higher than has so far been recorded for the

species (Gaskin 1968, Brown 1973), and is 1,2°C higher than is known for *L. borealis* (Leatherwood and Walker 1979). At Marion and Prince Edward Islands, the thermosalinograph reading of surface temperature was 5,2°C. This is considerably lower than the lowest recorded temperature of 9°C for *L. peronii*. However, there have been several sightings close to the Antarctic Convergence off Cape Horn (refer Fig. 1) where temperatures could be expected to range between 2 and 8°C. Brown (1973) has noted that, like the present sightings, all previous records of *L. peronii* north of the Subtropical Convergence are from cold water currents or upwelling systems. Apart from the northern extensions of its range reported here, the species appears to be confined to the zone between the Antarctic and Subtropical Convergences.

Gaskin (1972) points out that all New Zealand sightings occurred "several miles from shore". Brownell (1974) states that *L. peronii* is an epipelagic species found in off-shore deep water, whereas Aguayo (1975) calls it a pelagic and coastal species.

The present sightings off South West Africa were made between 35 and 65 nautical miles (mostly ± 50 miles) off shore on the outer edge of the continental shelf. Although the Marion Island sighting was less than five miles from the shore, the water depth was 500 m. It must be noted that, around Marion and Prince Edward Islands, the land shelf only extends 1 — 2 miles off shore and the depth of the water between the islands can exceed 500 m. This sighting should therefore be regarded as a deep-water record and not an inshore or shelf-water sighting. The sightings off South West Africa occurred where the depths were 300 — 500 m, and *L. peronii* should therefore be considered a deep-water species in the South-East Atlantic and southern Indian Oceans. Leatherwood and Walker (1979) describe the distribution of *L. borealis* as being seasonally over the outer shelf of California, but normally off the shelf.

Available food items

Bongo-net samples were taken obliquely from 50 m to the surface and continuous acoustic records were made at the time of the sightings. They were examined and compared for possible sources of food where the schools showed particular attachment to one area. It is concluded from the results and comparisons that the area associated with the South West Africa sightings has an abundance of the myctophid lantern-fish *Lampanyctodes hectoris*, and that the euphausiid *Nyctiphanes capensis* a small squid *Lolinguncula* sp. are also comm This conclusion is verified by the results of regu acoustic and ichthyoplankton surveys in the ar Torres and Aguayo (1979) found 1 261 lante fish otoliths and 46 beaks of mesopelagic sq species in the stomach of a single *L. perc* specimen caught 10 — 12 miles off the coast central Chile.

Lantern-fish (Myctophidae) and squid spec were the most common food items encounte in *L. borealis* stomachs (Leatherwood and Wall 1979).

HISTORICAL RECORDS

The detailed distribution of *L. peronii* is s little known, and all records of its occurrence a therefore of interest. Table II lists six histori records not previously referred to in studies of t species (Fig. 1).

In his account of distribution, Fraser (19 gives as his earliest record the specimen record by Péron near Tasmania, during the voyage of t *Géographe* and the *Naturaliste* (1800 — 1804). T specimen was used for the type description Lacépède who named the dolphin for Pérc However, the species was seen and described, b not named, by Banks during the voyage of t *Endeavour* more than thirty years earlier. Banl entry in his journal for 17 February 1769 (Beagleh 1962) states, ". . . saw several porpoises witho any pinna dorsalis, black on the backs and on t noses white." The position was approximately 46° 98°W in an area of the South-East Pacific Oce where sightings have not otherwise been reporte In addition to this definite record, Banks giv three other possible sightings east of New Zealan in the southern Pacific, but his descriptions a not sufficient to make the identification certa and they are therefore not considered here.

The other five records are from sperm- ar right-whaling voyages of three American whalin vessels and are of animals seen or harpoone Mitchell (1975) refers to this species being caug sporadically by whalers in the nineteenth centur but gives no details. The animals were taken t provide fresh meat on board. These records indica that the dolphins approached close enough to th vessel to enable them to be harpooned, and the probably rode the bow-wave as described in th new sightings from R.S. *Benguela*.

The positions of all five records lie within c

Table II: Historical records of the southern right-whale dolphin *Lissodelphis peronii*

Date	Position	Number of animals	Vessel	Source
1769	*ca* 46°00'S 98°00'W	several	*Endeavour*	Beaglehole (1962)
1839	*ca* 48°00'S 156°00'E	school	*Emerald*	Nichols (1973)
1839	50°15'S 179°13'E	school (1 struck but lost)	*Emerald*	Nichols (1973)
1839	*ca* 38°30'S 35°00'W	a great many	*Emerald*	Nichols (1973)
1844	46°34'S 158°32'W	1 harpooned	*Lucy Ann*	Martin (unpublished manuscript)
1847	37°03'S 11°36'W	1 harpooned	*Samuel and Thomas*	Hersey (unpublished manuscript)

e to the zone of West Wind Drift between the arctic and Subtropical Convergences. The *Lucy* record, which lies just north of the Subtropical vergence as plotted on Fraser's (1955) chart, two records from the *Emerald* are in the tern Pacific Ocean in areas where other sightings known. The third *Emerald* record and that the *Samuel and Thomas* are in the South antic Ocean, east of 45°W. Both records lie north of the Subtropical Convergence. They in a region where there are only two previously rted sightings. One is the record of three or animals seen on 24 October 1926 in 38°34'S, 5'E by Dr J. E. Hamilton. Fraser *(op. cit.)* gives for this sighting, but inspection of the original ublished record confirms that the date should 926. The other is an undated sighting of five als about 250 miles S.S.E. of Gough Island 4°S, 7°W) noted in Mörzer Bruyns (1971).

three of the *Emerald* records refer to "black- seen on the same day as the dolphins, but may not have been seen at the same time nor been in association. There is no mention ther species nor of the number of dolphins ent in the *Lucy Ann/Samuel and Thomas* rds, but both journals include a sketch of the al which was harpooned and these confirm identifications.

DISCUSSION

he sightings of *L. peronii* reported here affect status of our knowledge of the distribution of species. The prediction that southern right- le dolphins might occur in the Benguela Current em off the South West African coast (Brown 3) has now been substantiated. Previous doubtful ords of the occurrence of the species in South ican waters (van Bree *in litt.* 1970 and 1975) are now supported and conviction is lent to the expectations of Barnard 1954) that the species may appear closer to the South African coast than Hamilton's sighting (Fraser 1955). The sightings from the South-East Atlantic and South-West Indian Oceans also confirm the circumpolar distribution postulated for *L. peronii* by Fraser *(op. cit.)*

Sightings have been reported for midsummer and autumn. The absence of sightings outside the period December — April suggests that the species is migratory and not resident in the area. The seasonality differs from the trend described for *L. borealis* off California, i.e. movement southward and inshore concurrent with the intrusion of cooler water during autumn and winter months and northward and off shore again with the return of warmer water in late winter and spring (Leatherwood and Walker 1979). The winter sighting off Marion Island may fit the northern hemisphere pattern better. It was associated with colder water than that which El-Sayed *et al.* (1979) described as Antarctic water off the Prince Edward Islands.

Reaction to the close approach of a ship from both historical records and present sightings is inconclusive.

Colour anomalies on the flippers, melon and body seem to be sufficiently variable to be of use in identifying individuals. External tags inserted into the surface tissues do not last long in dolphins owing to tissue rejection processes in their skin (Nishiwaki *et al.* 1966, Tayler and Saayman 1972, G. J. B. Ross, Port Elizabeth Museum, personal communication), although some well-placed flat tags similar to those used for ear-tagging and spaghetti tags have lasted up to two and over four years respectively (Norris and Pryor 1970, Evans *et al.* 1972). Freeze branding may also be more permanent (Evans *et al., op. cit.*), and underwater paint marking has been used with short-term success by Watkins and Schevill (1976).

A permanent means of individual recognition in the field would be of great value in behavioural studies and in monitoring seasonal movements of the species should the opportunity arise to monitor any groups for a sustained period. Recognition of distinctive individuals could help elucidate sub-groups within various aggregations, the number of schools within a given study area, and in following behaviour of individuals within a school. The distinctive colour variations noted (Fig. 3) in December 1978 were not observed in any of the subsequent sightings. Differences of flipper markings (Figs. 2 and 4) allowed certain individuals from a large group to be monitored for a prolonged period at one sighting. Variations in body markings and injury marks have been used in studying captive bottlenose dolphins *Tursiops aduncus* (Tayler and Saayman 1972) and in the wild for humpback whales *Megaptera novaeangliae* (Katona *et al.* 1979).

It is therefore not inconceivable that this technique could be applied to southern right-whale dolphins if the variations of colour pattern are carefully noted and photographed.

ACKNOWLEDGEMENTS

Thanks are due to Dr P. B. Best for historical data on skulls reported to have come from southern Africa and also for assistance and helpful criticism in researching and compiling this report. He also drew our attention to the *Samuel and Thomas* record. Dr K. R. Martin, Director of the Kendal Whaling Museum, brought the *Lucy Ann* record to our attention and generously allowed us to publish both records from the manuscript journals held in the museum. Dr P. J. H. van Bree is thanked for checking and detailed comment on historical data and specimens in the Amsterdam, Paris and Leyden Museums. Dr G. J. B. Ross of the Port Elizabeth Museum, Dr S. Leatherwood of Hubbs-Sea World Research Institute and Mr A. I. L. Payne are thanked for editorial comment, Mr P. E. Malan for the use of some of his photographs and Messrs J. A. Campbell and P. E. Malan for photographic processing.

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DISTRIBUTION, AVAILABILITY AND MOVEMENTS OF MACKEREL *SCOMBER JAPONICUS* OFF SOUTH AFRICA, 1964-1976

R. J. M. CRAWFORD

Powerful 1966 and 1967 cohorts provided high yields of mackerel *Scomber japonicus* during the late 1960's. Landings have since declined. Purse-seine catches have frequently been recorded some distance off shore, but seldom from north of latitude 31°S or east of Quoin Point. Nought-year-olds are fully recruited at the start of the fishing season in January, when they are most abundant north of Cape Columbine. Subsequently they move south, but availability decreases sharply in winter, possibly as a result of an off-shore migration to the areas where lantern-fish *Lampanyctodes hectoris* are abundant. Zooplankton continues to form an important component of the diet of one- and two-year-old mackerel, which are present in the major upwelling regions during summer and early autumn. Again availability decreases towards winter. Fish aged three years and older are generally sexually mature and occur in off-shore waters north of Cape Town. They move inshore to spawn in autumn and winter, when the highest catch rates of adults are recorded. Future good year-classes should be detectable early, because of the nearshore distribution of young fish during the greater part of the fishing season.

Sterk jaarklasse gedurende 1966 en 1967 het gesorg vir hoë opbrengste van makriel *Scomber japonicus* gedurende die laat sestigerjare. Sedertdien het vangste gedaal. Beursnetvangste word gereeld aflandig aangeteken, maar selde noord van breedtegraad 31°S of oos van Quoinpunt. Die nul jaar oue visse is aan die begin van die seisoen in Januarie ten volle gerekruteer wanneer hulle die volopste noord van Kaap Columbine is. Hulle beweeg daarna suid, maar beskikbaarheid daal skerp gedurende die winter weens 'n aflandige migrasie na die vanggronde van die lanternvis *Lampanyctodes hectoris*. Soöplankton vorm steeds 'n belangrike komponent in die dieet van een en twee jaar oue makriel wat in die vroeë herfs en somer in die opwellingsgebiede voorkom. Weer eens neem die beskikbaarheid af met die naderende winter. Vis van drie jaar en ouer is in die algemeen geslagsryp en kom in die aflandige waters noord van Kaapstad voor. Gedurende herfs en winter, wanneer die hoogste vangkoers vir volwassenes aangeteken word, beweeg hulle aanlandig om kuit te skiet. Toekomstige goeie jaarklasse behoort in 'n vroeë stadium vasgestel te kan word weens die aanlandige verspreiding van jongvis gedurende die grootste gedeelte van die visvangseisoen.

Mackerel *Scomber japonicus* made its first appearance in the South African purse-seine fishery in 1954 and, as a result of exceptionally good 1966 and 1967 year-classes (Newman and Crawford 1980), became one of the major contributors to the combined mixed-species catch during the late 1960's (Table I). By this time the age structure of the pilchard *Sardinops ocellata* stock had been considerably reduced through the introduction of a small-meshed (12,7-mm) net, and pilchard sufficiently large for canning were seldom encountered in the vicinity of factories capable of processing them to this form of end product (Crawford *et al.* 1980). Therefore, for the fishing industry, the increased abundance of mackerel came at a most opportune time, and it allowed the overall production of canned fish to be maintained at a moderate level for a number of years (Table II). Further strong recruitment failed to materialize, however, and the mackerel population declined in a manner similar to that earlier evidenced by the horse-mackerel *Trachurus trachurus* and pilchard resources, with disastrous results for the industry.

The reasons for these declines have been and remain the subject for much speculation. Recent opinion is that they were precipitated by returns to more normal levels of recruitment after large,

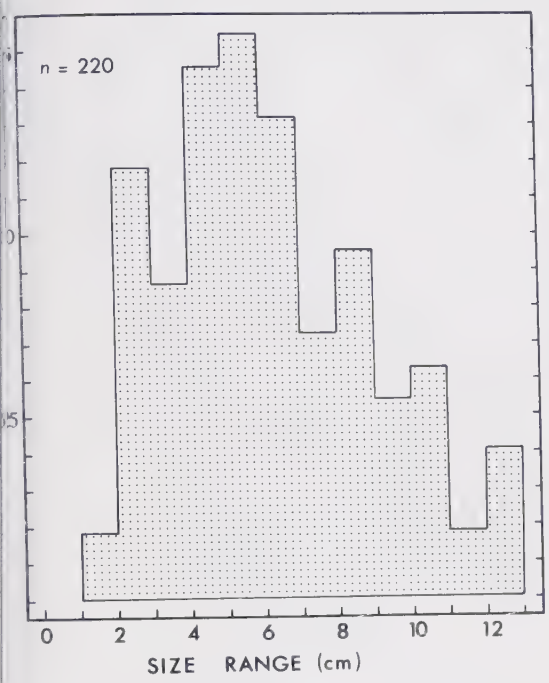
Table I: Landings of mackerel and their contribution to the total South African purse-seine catch, 1954-1976*

Year	Landings (metric tons)	Proportion of total combined landings (%)
1954	4 044	1,9
1955	20 228	9,2
1956	32 593	21,0
1957	7 364	3,7
1958	21 580	7,9
1959	33 088	10,5
1960	30 985	7,5
1961	49 690	10,1
1962	20 355	4,1
1963	13 201	3,1
1964	50 024	11,8
1965	41 426	8,6
1966	53 426	15,0
1967	128 219	25,2
1968	91 023	24,7
1969	91 702	26,1
1970	77 939	21,7
1971	54 206	16,7
1972	56 680	13,1
1973	58 835	13,0
1974	30 665	7,7
1975	69 344	17,0
1976	546	0,1

* No landings of mackerel were recorded prior to 1954

Table II: Production of fish meal, fish oil and canned fish from the South African purse-seine fish landings, 1950—1976

Year	Purse-seine catch (thousand metric tons)	Fish meal (thousand metric tons)	Fish oil (thousand metric tons)	Canned fish (metric tons)				
				Pilchard	Horse mackerel	Mackerel	Round herring	Total canned fish
1950	135,2	21,6	8,5	6 155	1 521	0	0	7 676
1951	200,4	31,3	9,6	5 164	4 615	0	0	9 779
1952	272,6	38,1	12,2	8 695	7 615	0	0	16 310
1953	217,7	31,3	11,3	16 411	7 949	0	0	24 360
1954	210,5	31,4	11,4	7 475	20 488	672	0	28 635
1955	221,0	37,3	10,9	7 614	8 119	1 842	0	17 575
1956	154,9	26 7	6,7	2 577	7 794	3 769	0	14 140
1957	201,5	37,2	10,3	3 903	8 227	607	0	12 737
1958	273,4	48,8	12,3	3 263	6 205	2 060	0	11 528
1959	314,9	64,9	15,1	419	3 140	5 798	0	9 357
1960	412,0	89,3	26,4	2 854	9 166	4 173	0	16 193
1961	490,9	108,7	40,9	9 404	5 012	5 432	0	19 848
1962	497,3	113,9	35,0	6 765	8 705	3 581	0	19 051
1963	427,0	100,8	28,4	7 722	1 897	1 585	0	11 204
1964	425,6	98,7	22,1	2 128	1 604	7 419	0	11 151
1965	480,1	112,5	20,4	1 318	4 635	4 478	0	10 431
1966	357,1	82,0	12,8	709	942	3 777	0	5 428
1967	509,3	115,8	17,5	71	132	3 669	0	3 872
1968	368,6	86,5	16,0	18	30	4 488	16	4 552
1969	352,0	80,0	20,1	7	1 168	4 561	30	5 766
1970	358,9	80,3	21,9	0	0	3 147	9	3 156
1971	324,9	74,2	16,5	54	0	3 237	32	3 323
1972	433,6	96,9	16,1	23	0	2 975	0	2 998
1973	451,4	98,4	24,4	105	16	3 348	7	3 476
1974	400,5	89,9	22,9	13	0	1 929	0	1 942
1975	407,4	97,8	14,2	349	0	3 822	47	4 218
1976	407,5	102,1	24,5	21	0	0	0	21



1: Frequency of occurrence of size ranges (caudal length) of mackerel sampled from individual commercial purse-seine catches

ral increases in population sizes, and also by detrimental influence of intensive fishing ssure on the younger age classes, spawning ks being reduced (Centurier-Harris *et al.* 1977, man and Crawford 1980). Whatever the cause, evident that, because of previous uncertainty t the population biology of component species, management strategies and economic planning in the fishery have been largely inadequate have led to considerable overinvestment of rt (Newman *et al.* 1979). It is also increasingly r that the sequential depletion of traditional urces (Crawford 1981c) is making the possibility improving or even maintaining current yields gressively more remote.

Barring drastic cutbacks in effort, which may entually prove inevitable but would probably sult in the elimination of a considerable number job opportunities, the industry faces two alternatives: diversification to exploit new resources improved utilization of the raw materials already ing harvested. Both these options may well come realities within the immediate future. The dustry is already showing increased interest in e first possibility. Fishing surveys were conducted off Port Elizabeth during November and December 1976 and June 1977, albeit with no success, and in 1978 permission was granted to 16 purse-seine vessels to experiment with the use of midwater gear. There is some danger that, should too much emphasis be placed on diversification without stricter control being applied to the present *modus operandi,* the successive elimination of more resources will follow, with the industry degenerating to the exploitation of less and less rewarding species. It is therefore of prime importance that consideration be given to the second alternative, which in itself presupposes an understanding of the distribution and availability of the various species involved in the fishery.

Preliminary analyses of trends in the commercial catches of mackerel have already been documented by Centurier-Harris and Crawford (1974) and by Baird (1978a). In this report, an attempt has been made to quantify patterns of behaviour through manipulation of catch and effort data collected between 1964 and 1976. Also, monthly distribution charts are employed to elucidate the behaviour of the two dominant year-classes of mackerel, and an attempt is made to establish a means of predicting, at an early stage, the likelihood of similar future occurrences.

DISTRIBUTION OF COMMERCIAL PURSE-SEINE CATCHES

Distribution patterns for commercial catches were derived in a similar manner to that which has been described for the pilchard population (Crawford 1981a). They are presented in chart form in the Appendix, catch rates being shown to depict regional differences in the density of fish. The modal length of fish caught in known localities has also been included, whenever this information was available from field observations, to give some idea of geographical and seasonal variations in the size of mackerel encountered.

Examination of the length distribution of mackerel in 220 purse-seine catches revealed that mackerel from any one shoal can differ in caudal length by up to 13,0 cm, but generally by not more than 7,0 cm (Fig. 1). It is possible, therefore, that modal length may give a somewhat biased picture in a few instances, but the incidence of such bias is expected to be low.

Age at maturity has been discussed by Baird (1977), who found that the onset of reproductive activity takes place when mackerel are in their

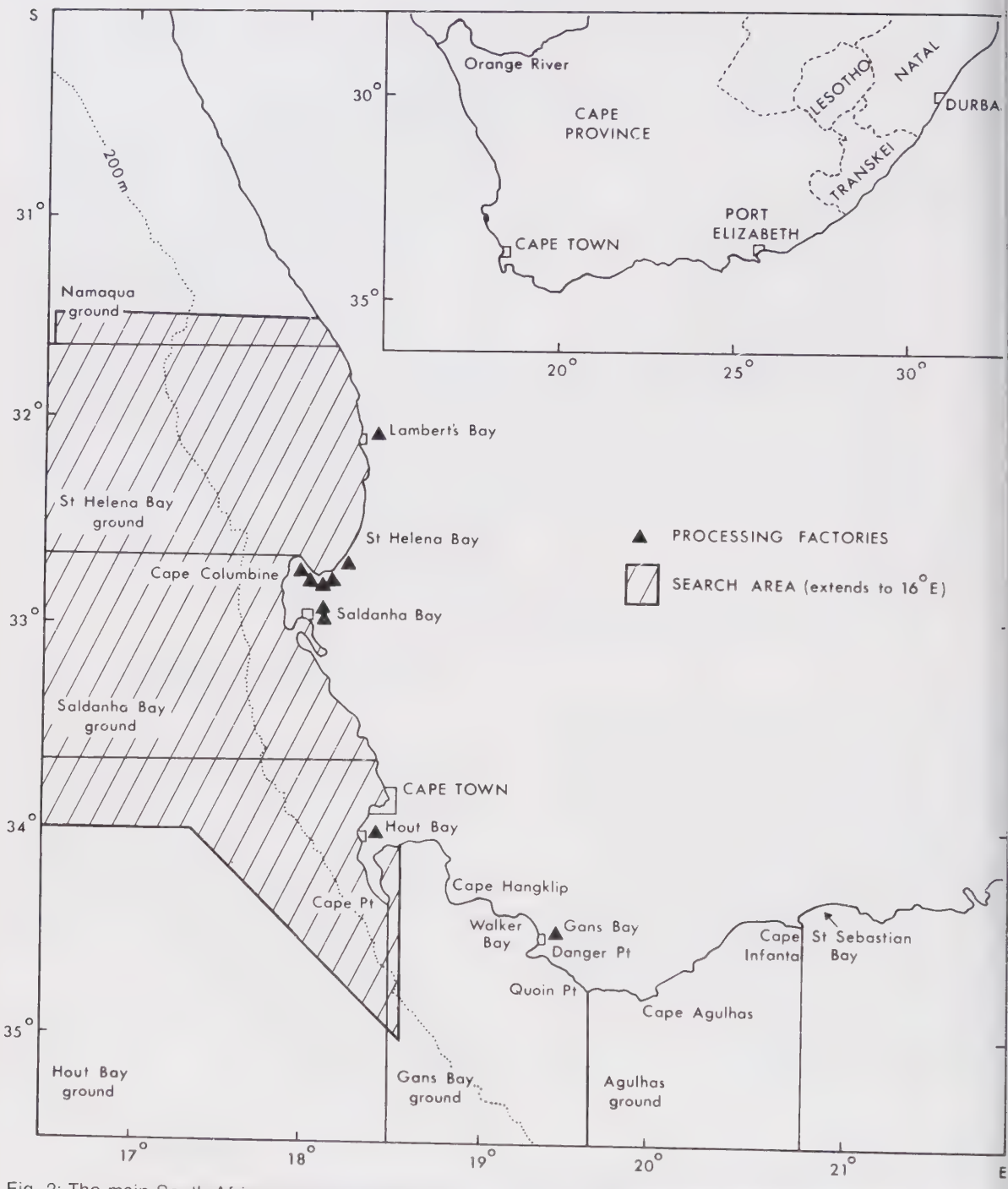


Fig. 2: The main South African purse-seine fishing grounds, the locations of the processing factories operative in 1976 and the area searched from the air in 1973 — the Namaqua ground extends north to the Orange River (inset)

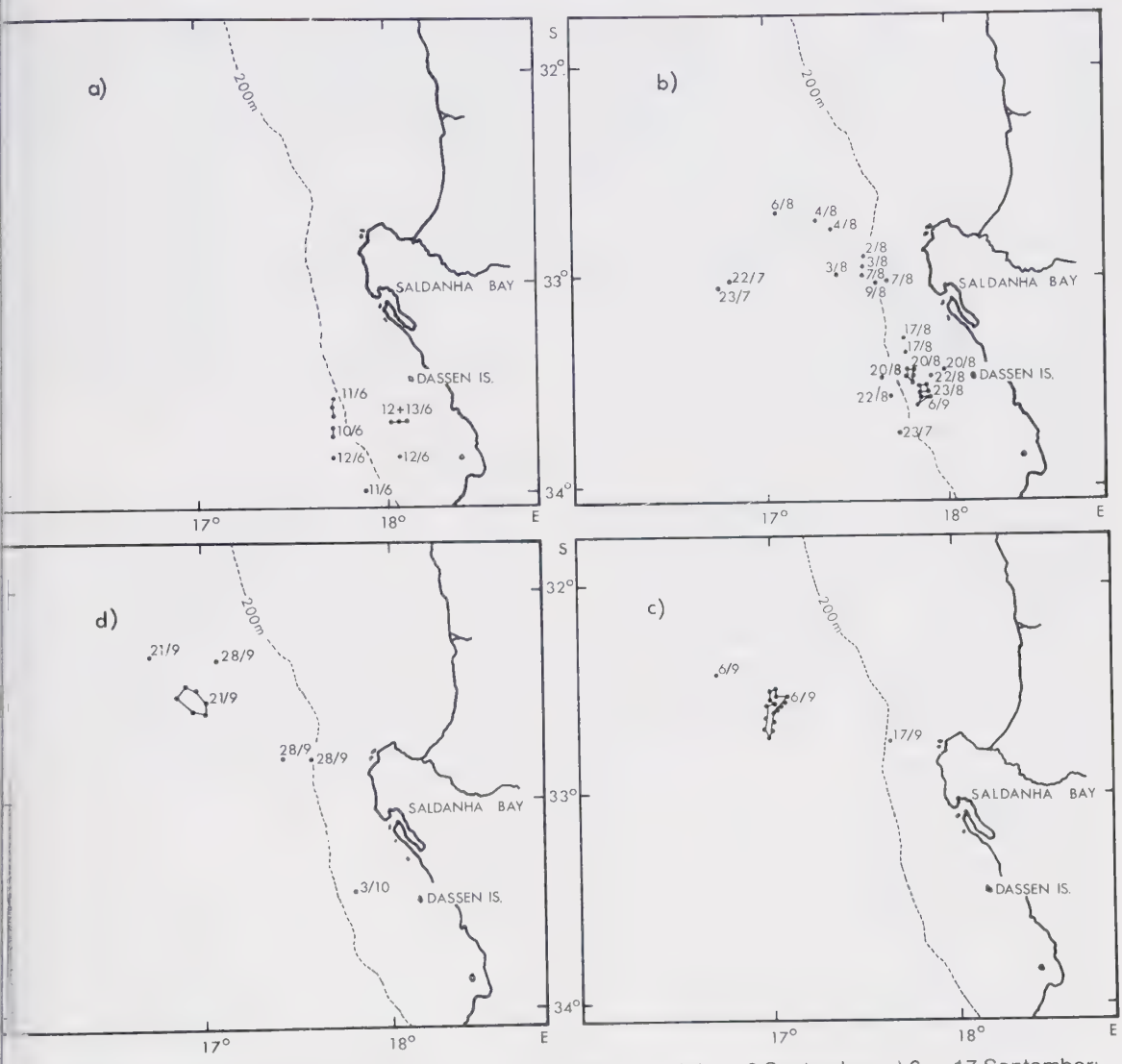


Fig. 3: Aerial sightings of mackerel in 1973: a) 10 — 13 June; b) 22 July — 6 September; c) 6 — 17 September; d) 21 September — 3 October

ird year. About 50 per cent are mature at three ears of age and all are mature before they turn ur. However, in order to conform on the Appendix harts with the procedure used for other species Crawford 1981a,b,d,e) and thereby to highlight e distribution of recruit year-classes, it was decided indicate only nought-year-old fish with the nading adopted for juveniles and all older age roups with that used for adults.

Reference to the charts in the Appendix reveals that, unlike other species involved in the fishery, mackerel occur fairly frequently some distance from shore. As noted by Baird (1978a), most offshore catches were made after the commencement of aerial fish spotting in 1967, and there seems little doubt that this innovation was largely responsible for persuading many skippers to forsake, on occasion, their innate tendency to remain close to the coastline. Instead, they ventured farther out to sea with the expectation of more rewarding

catches. After locating fish the aircraft often remained in the immediate vicinity, directing boats on to individual shoals. Another reason for the skippers becoming more adept at fishing with deeper nets was the expertise gained from the charter in 1968 of a large Norwegian purse-seiner with crew experienced in deep-water herring fishing in the North Sea.

All off-shore catches have been on the St Helena Bay, Saldanha Bay or Hout Bay grounds and none have included nought-year-old fish. Nearshore catches have ranged as far north as the Orange River (three-year-old fish in April and June 1966) and eastward to Cape Infanta (one-year-olds in March 1967 and March 1973), but records north of latitude 31°S or east of Quoin Point have been infrequent, and most fishing for mackerel is confined to the intervening areas.

Hecht (1976) noted that small quantities of mackerel (less than 25 tons annually) are caught by the demersal fishery off the Eastern Cape coast. The maximum total length he recorded was 23 cm, which suggests that all are less than one year old.

Additional information on the distribution of mackerel off the West Coast between 9 June and 16 October 1973 is available from observations made from the commercial fish spotter *Oceana Maan*. Some 310 hours were spent in the air, mostly at night and in the absence of bright moonlight, thus ensuring optimal conditions for spotting. In the Benguela Current system, species of luminescent phytoplankton are sufficiently numerous to clearly outline the shape of fish shoals moving through them at night (Cram 1974) and, on all night flights, spotlights were regularly flashed at the water's surface in an attempt to stimulate immobile or slowly moving fish to greater activity. After such stimulation, mackerel shoals tend to "glow" brightly for periods of up to 60 seconds but, when subjected to repeated flashing, they often sound to greater depths. Confirmation of airborne identification of mackerel was provided by purse-seine catches made in August 1973. The area searched is shown in Figure 2 and the positions of all shoals sighted in Figure 3. The areas and positions substantiate the catch patterns noted during similar months between 1968 and 1973.

AVAILABILITY, ABUNDANCE AND MOVEMENTS

Monthly indices of availability and of the relative abundance of fish that could, on average, be expected to be present on each of six fishing grounds (Fig. 2) were determined for three a components of the mackerel population. Th method employed was analogous to that previous adopted for the pilchard resource (Crawford 1981a and the three age categories were those distinguis ed by Baird (1978a), i.e. nought-year-olds, fis aged one or two, and all older individuals. For th youngest age class only the period 1966 — 197 was considered, because nought-year-old fish we not fully selected by the fishing gear in earli years. No values were calculated for Octobe November or December, insufficient fishing bein conducted during these months. The resultin estimates, expressed as percentages of the maxim appear in Figures 4 and 5.

Spawning

Baird (1977) defines the spawning season c mackerel as June — September. During thes months in 1973, the largest concentrations of egg were encountered between Lambert's Bay an Dassen Island in water temperatures of 11,5 - 16,9°C and in salinities of 34,70 — 35,59‰ (Bair 1975). The area roughly coincided with the distri bution of reproductively active mackerel (Fig. 3) leading Baird (1978a) to speculate that the frequen winter appearance of these older age groups wa linked with spawning.

Nought-year-old fish

Nought-year-old mackerel are fully recruited by the start of the fishing season in January each year, seven months after the initiation of spawning and availability remains at a moderate level unti May. In winter catch rates drop sharply (Fig. 4) An unrealistically high value of total mortality ($Z = 3,7$) would be required to account for the observed decline and, although there appears to be a southward shift in the distribution of this age class from north of Cape Columbine in summer to the Saldanha Bay, Hout Bay and Gans Bay grounds in winter (Fig. 5), no longshore migration off the fishing grounds is evident. These young mackerel are often found in association with adult round herring *Etrumeus teres* (Baird 1978a), which exhibit similar trends in behaviour (Crawford 1981e), and it is possible that both move away from the coast in winter. The importance of lantern-fish *Lampanyctodes hectoris* in the diet of one-year-old mackerel (Baird 1978b) could be the cause of the migration to deeper water.

Although catch-per-unit-effort levels greater than

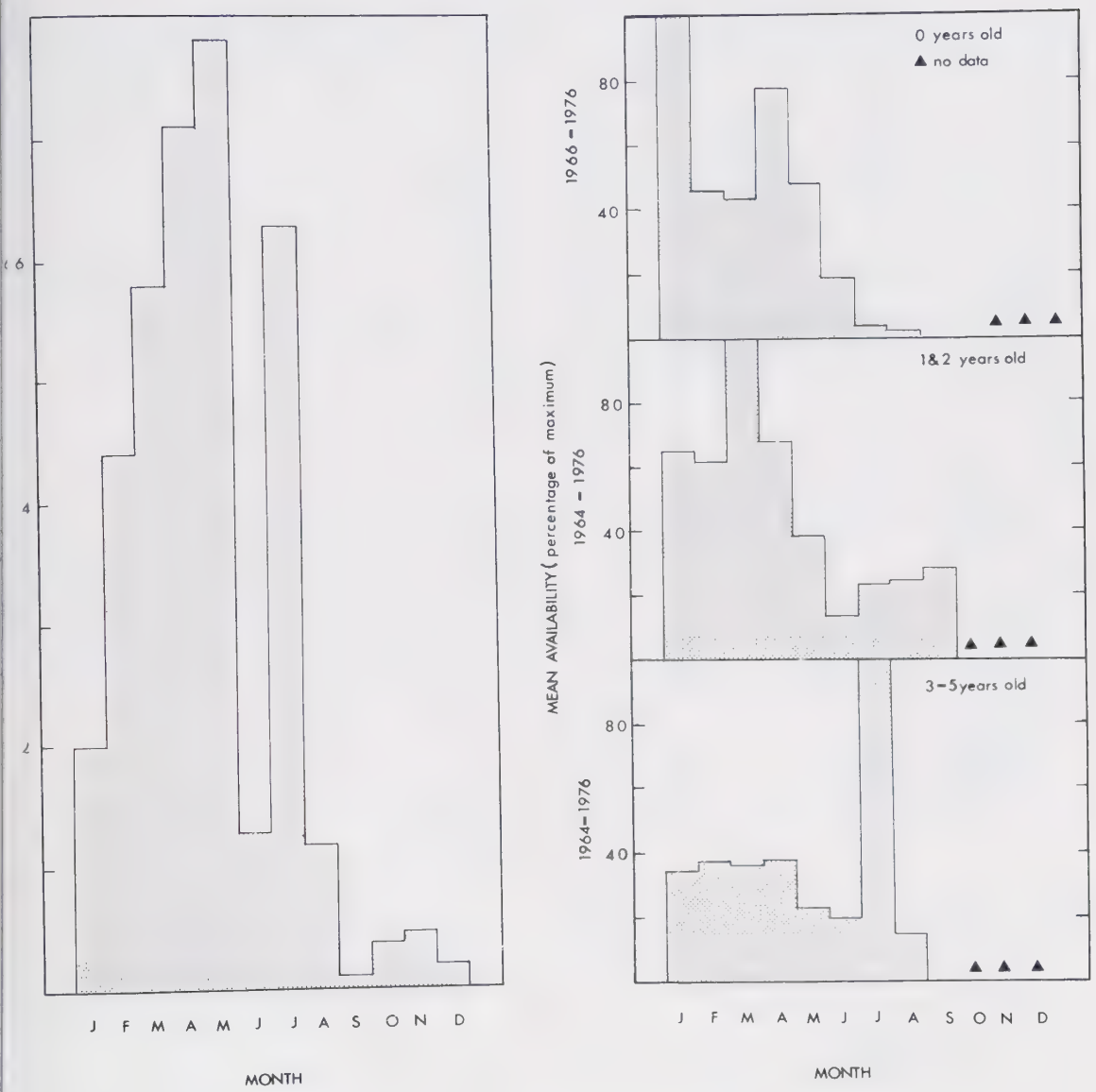


Fig. 4: Age-specific monthly availability indices for mackerel off South Africa

metric tons per standard-boat-day have not requently been found for the period January — ay, they have never been recorded for winter nths (Table III). Nevertheless, the pattern is t altogether regular, because nought-year-old ackerel often failed to contribute in significant antities to the landings at any time during the ason. This fact is illustrated by the age composi- n of the commercial catches (Fig. 6) in 1965, 1968, 1972, 1973, 1974 and 1975. Also, catches of all age groups were exceptionally poor during 1976 (Crawford *et al.* 1978).

One- and two-year-old fish

One- and two-year-old mackerel are also most available during summer and autumn, catch rates

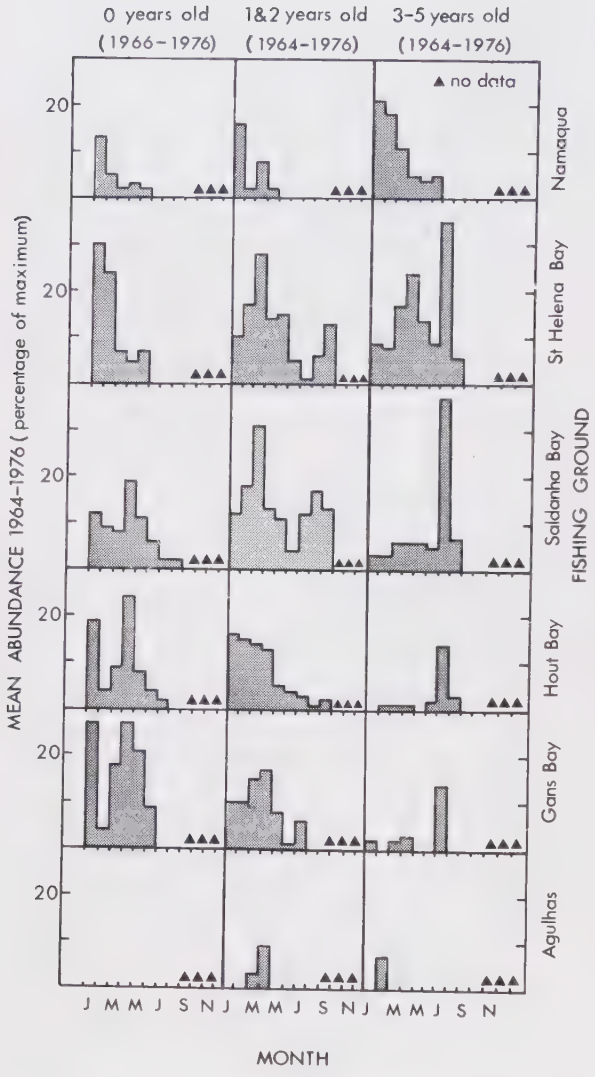


Fig. 5: Age-specific monthly abundance indices for mackerel for six fishing grounds

declining to a lower level in winter (Fig. 4). As noted by Baird (1978a), the best catches of these age groups are made on the St Helena Bay and Saldanha Bay grounds, although reasonable catches are made on the Hout Bay and Gans Bay grounds as well (Fig. 5). These mackerel show an increasing preference for lantern-fish as food, but zooplankton continues to form an important component of their diet (Baird 1978b), which probably accounts for their presence in the major upwelling regions

Table III: Months in which catch rates greater than 1 tons per standard-boat-day were recorded for nought-year-old mackerel, 1964–1976

Month	Season
January	1966, 1967, 1969
February	1966
March	1964, 1966
April	1966, 1967, 1971
May	1964, 1966, 1967, 1971, 1972
June	—
July	—
August	—
September	—
October	—
November	—
December	—

during summer and early autumn.

Catch-per-unit-effort levels greater than 25 metri tons per standard-boat-day have been most fre quently recorded in summer and autumn, bu equally rewarding fishing has taken place in som months during winter and early spring, especiall since the introduction of aerial fish spotting ir 1967 (Table IV).

Three- to five-year-old fish

The adult component of the mackerel stock is made up of three- to five-year-old fish (Fig. 6). Availability indices show a noticeable peak in July and lower levels during other months (Fig. 4). The

Table IV: Months in which catch rates greater than 25 tons per standard-boat-day were recorded for one- and two-year-old mackerel, 1964–1976

Month	Season
January	1964, 1968, 1969, 1975
February	1964, 1967, 1975
March	1964, 1967, 1973, 1974
April	1964, 1968, 1972, 1974
May	1964, 1968, 1969
June	1975
July	1964, 1968, 1969
August	1969, 1971, 1973
September	1971
October	—
November	—
December	1964

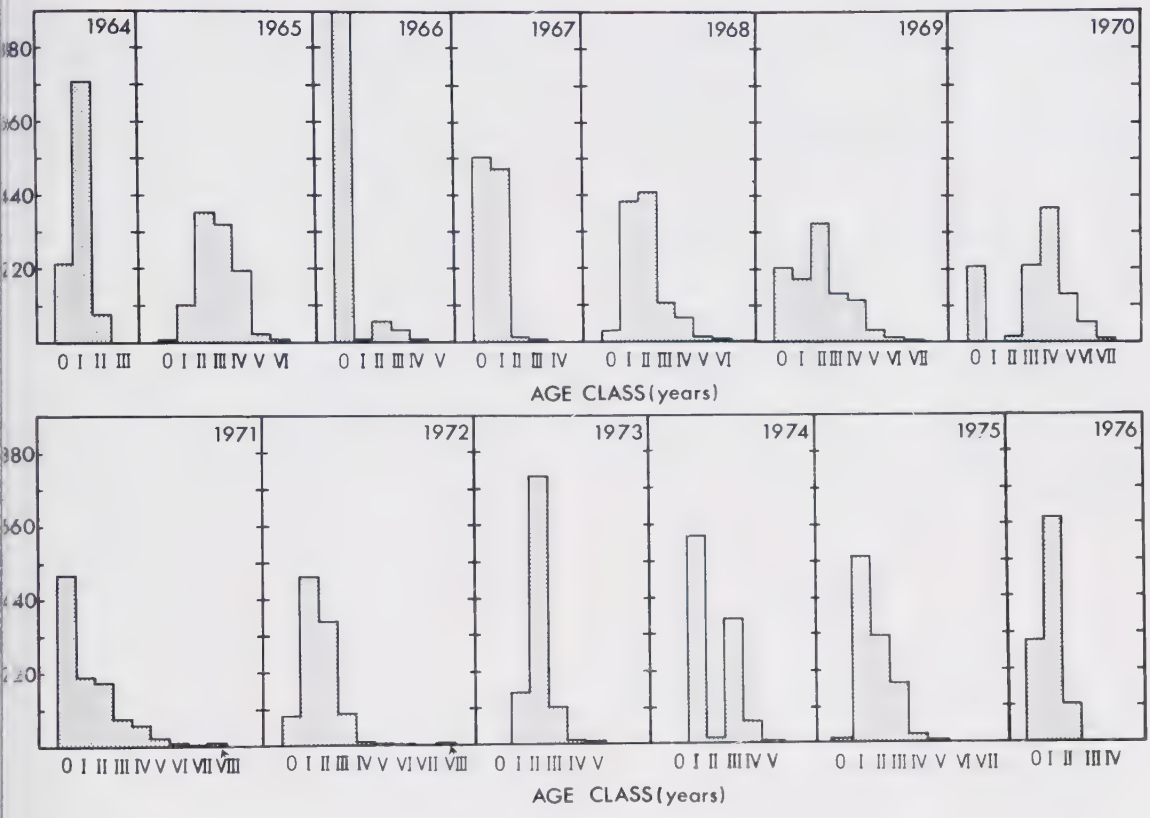


Fig. 6: Age composition of South African purse-seine mackerel landings, 1964 — 1976 (data after Crawford *et al.* [1978])

ptness of this pattern is difficult to explain, it may in part have resulted from a lack of quate data. An attempt was made to gauge its bility by calculating mean monthly catch rates mackerel over the period 1954 — 1963, when aged three and older made the only significant tribution of the species to the landings (Crawford *al.* 1978). The effort during any particular month s allocated to individual species *pro rata* to ir contribution to the combined catch.

The result is a steady increase in availability ring late summer and autumn, with high catch es in July, but availability dropping rapidly there- er (Fig. 4). This trend is possibly more realistic, nough again there is no satisfactory way of counting for the poor returns in June. On the ner hand, the discrepancy between the two tterns could have been influenced by the roduction of aerial fish spotting in 1967. Refer- ce to the Appendix reveals that levels of catch per unit effort greater than 25 metric tons per standard-boat-day were recorded in January 1965 and 1968, March 1965 and 1967, April 1964 and 1966, May 1966 and 1969, June 1969 and 1970, July 1968, 1969, 1970, 1971, 1972 and 1975 and August 1973. Of these, the last 10 instances may all be attributed to fish spotting.

The distribution of the three- to five-year-old mackerel is largely confined to the three northern-most fishing grounds (Fig. 5), with only isolated catches being made further south. During summer, catch rates are highest off the Namaqua coast, but later in the year the St Helena Bay and Saldanha Bay regions are most productive. Although large quantities of zooplankton continue to be ingested, lantern-fish predominate in the diet of this component of the mackerel population (Baird 1978b), and it is noteworthy that the bulk of the lantern-fish catch is recorded from similar areas (Crawford 1980).

Baird (1978a) describes an off-shore to inshore migration of adult mackerel during the winter months. He relates this to spawning and to an onshore current set in motion by north-westerly winds that bring relatively warm (14 — 15°C) water nearer to the coast (Shannon 1976). The migration generally takes place in the vicinity of Cape Columbine, the mackerel often moving later in a southerly direction as far as Dassen Island (Baird 1974). These trends are clearly apparent from the positions of shoals sighted from the air between 22 July and 6 September 1973, between 6 and 17 September 1973, and between 21 September and 3 October 1973 (Fig. 3). Also, southward movements of three-year-old fish between April and May 1967 and between March and August 1968, of four-year-olds between June and July 1969 and of five-year-olds between June and July 1971 are evident from the charts in the Appendix.

DISCUSSION

The performance of the mackerel fishery has been dominated by the two exceptionally good year-classes of 1966 and 1967. The development of these two cohorts is easily traced on the distribution charts in the Appendix.

Nought-year-old fish were relatively scarce in 1964 and 1965, but during January 1966 they were caught over a large area, especially good returns coming from north of the Olifants River and from west of Hout Bay. From February to May they continued to contribute good catches, primarily in the vicinity of Dassen Island or north-west of Cape Columbine and, although availability declined towards the end of the season, there was a notable build-up of one-year-olds between Saldanha Bay and Hout Bay in February 1967.

The stage was thus prepared for the remarkable landing of 91 774 metric tons of mackerel in March 1967, an amount greater than the total mackerel catch of any other year. Almost all of this (90 343 tons) came from the area between Saldanha Bay and Cape Point for, although good catch rates were experienced elsewhere, levels of effort were low. Had it not been exceptionally powerful, such intensive exploitation could well have destroyed the cohort. However, it reappeared in the same vicinity in May 1968 and was harvested successfully until August. It is of interest to note that, in July, its distribution tended to be off shore, being centred on the 200-m (100-fm) bottom contour outside Dassen Island. Catches made north of Cape Columbine during July were mainly of four-ye old fish, but all other mackerel landed betwe May and August were from the 1966 year-class.

Following sporadic catches in January 1967, t 1967 cohort began to reveal its full potential April, catch rates greater than 25 tons per standa boat-day being recorded in the vicinities of Dass Island and Cape Point and outside False Bay. T next year, one-year-old fish were abundant, especi ly during the first four months. Again the m productive region was between Saldanha Bay a Cape Point but, although catches were made bo near to the shore and outside the 200-m isobat they never attained the level of the previous Marc The best yields from this year-class in 1969 we made during late autumn and winter, initially arou Dassen Island and later north-west of Cape Colu bine. The March and April catches outsi Lambert's Bay had, in the meantime, been don nated by the 1966 cohort.

From 1970, the 1966 and 1967 year-classes a best considered together. They appeared outsi Dassen Island in June and July 1970, midw between Port Nolloth and Lambert's Bay in Ju 1971 and from the Olifants River to Hout Bay July 1971. In both these years, especially in 197 the distribution often extended a considera distance off shore. By this stage, however, the tw cohorts were beginning to disappear from t fishery (Fig. 6), and the mackerel catch gradual declined (Table I).

It is possible to trace other less prominent ye classes in a similar manner, but these two suffi to demonstrate that the trends illustrated in Figur 4 and 5 are an adequate description of the typic behaviour of the mackerel population. They al confirm Baird's (1978a) observation that the speci tends to assume a more off-shore distribution as grows older, probably because of the progressi change in its diet (Baird 1978b). Because of t inshore location of the younger age groups a their preference for the central fishing grounds, might be expected that any dominant year-cla would provide significant yields during its first fu year in the fishery, or at least before attaining th age of two, as was the case during 1966, 1967 an 1968. Bearing in mind the very real possibility over-exploitation at these early stages, similar goo catches could be a pointer to profitable years t come. Reference to Table I reveals that this w not the situation during 1976 when the catch w the lowest on record.

Evidently the mackerel population will requi careful management in future years to establis and maintain an adult stock that is capable

n producing such favourable recruitment. In , 1974 and 1975 the South African purse- fishing season was extended and additional as were granted specifically for the capture dult mackerel. In retrospect this does not ar to have been a wise move, and it is mmended that it should not be repeated in re.

ACKNOWLEDGEMENTS

hank Professor J. G. Field (University of Cape n), Dr G. G. Newman and Messrs R. M. Smith A. I. L. Payne for commenting on the original uscript. I am also grateful to my wife, Phyllis, F. Kriel and other technicians of the Sea eries Institute for assistance with the artwork data manipulation. The study was supported grant from the Fisheries Development Corpo- n of South Africa Ltd.

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This report is based on a section of a dissertation submitted in September 1979 as part requirement for the degree of Doctor of Philosophy at the University of Cape Town.

APPENDIX

MACKEREL CATCH LOCATIONS 1964—1976

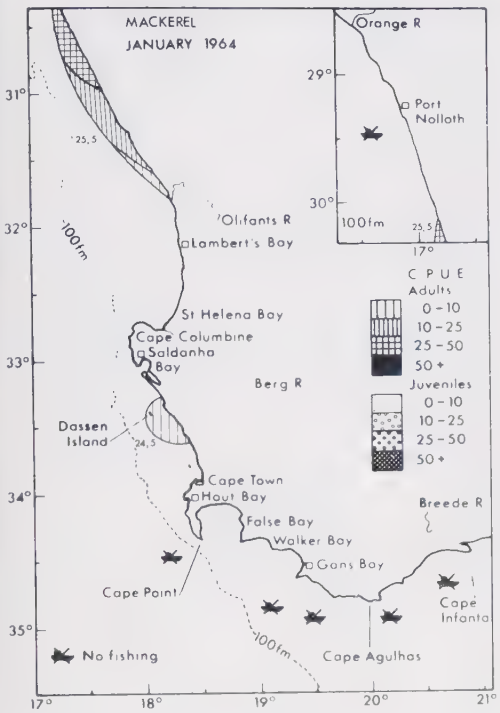
From 1969 to 1970 and 1972 to 1976 no maps are shown for September — December inclusive, because exploitation of mackerel was prohibited during these months, except for September 1973 and 1974 when no catch was recorded.

Levels of catch per unit effort (C.P.U.E.) are indicated as metric tons per standard-boat-day.

Modal caudal lengths (cm) of fish from different areas are shown adjacent to catch locations. Growth rates may be expected to vary between seasons, but some indication of age is provided by the von Bertalanffy growth equation calculated by Baird (1977).

Age (years)	Predicted caudal length (cm)
1	23,1
2	31,3
3	38,2
4	43,8
5	48,3
6	52,0
7	55,0
L_∞	68,0

Areas in which there was no deployment of fishing effort are shown.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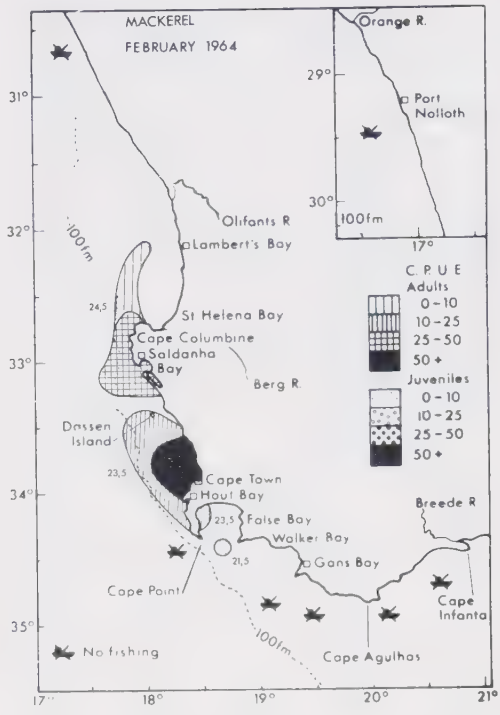
JANUARY 1964
Orange R
Port Nolloth
29°
30°
100fm
25,5
17°
31°
32°
33°
34°
35°
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
24,5
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
17°
18°
19°
20°
21°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Olifants R
Lambert's Bay
24,5
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
23,5
Cape Town
Hout Bay
False Bay
Walker Bay
21,5
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
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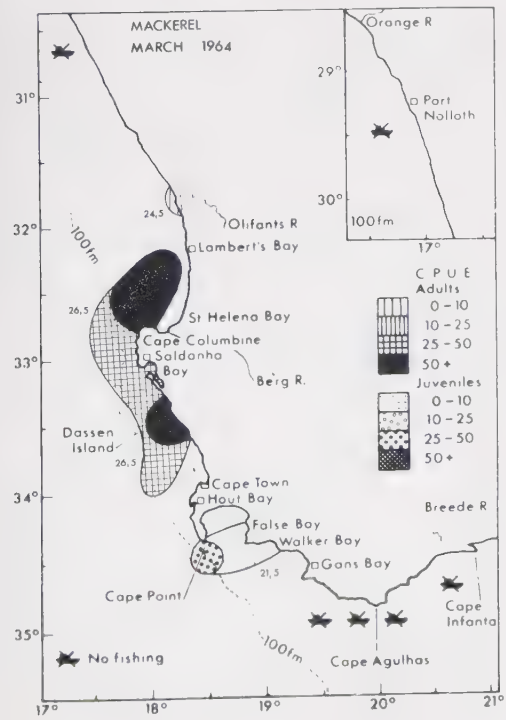
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Lambert's Bay
26,5
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
26,5
Cape Town
Hout Bay
False Bay
Walker Bay
21,5
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
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25 – 50
50 +
Juveniles
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25 – 50
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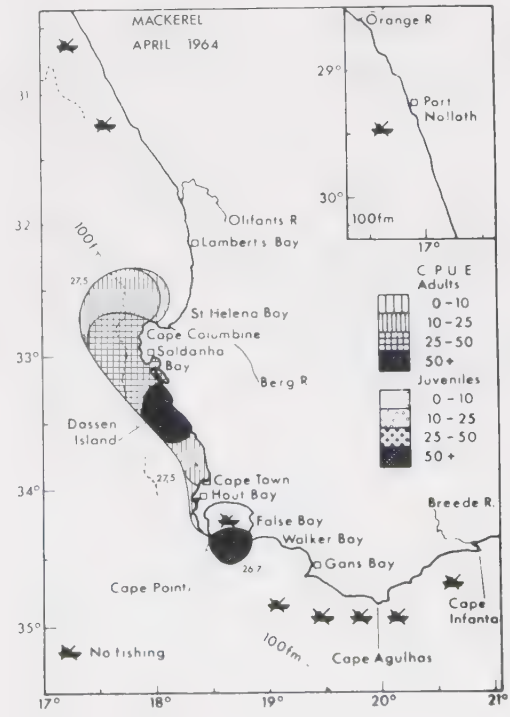
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Dassen Island
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No fishing
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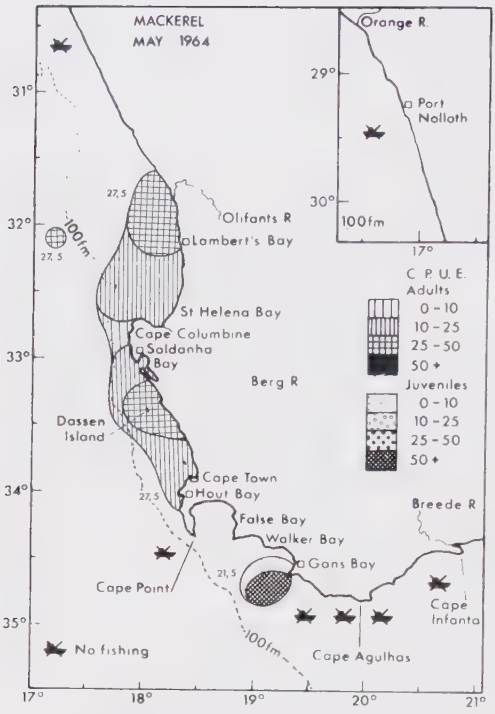
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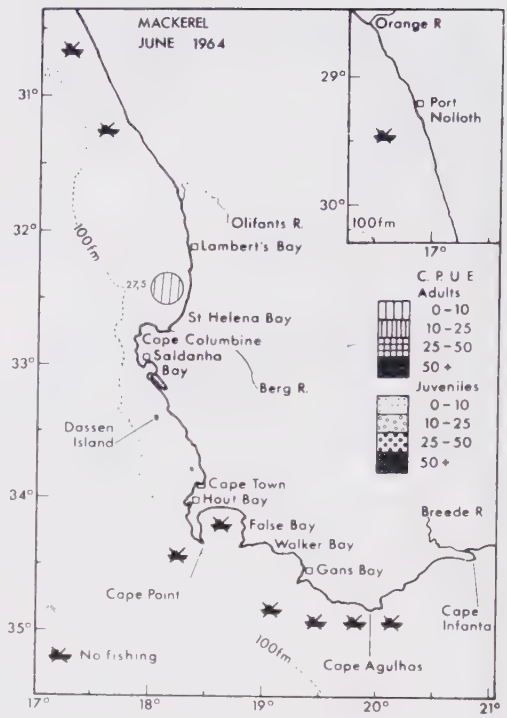
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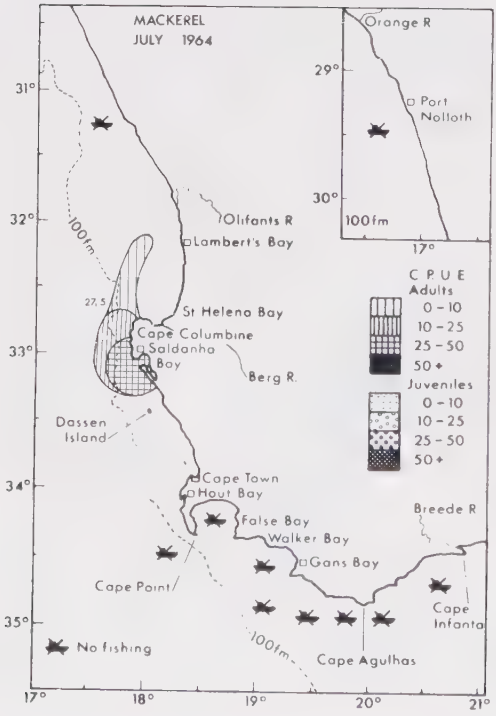
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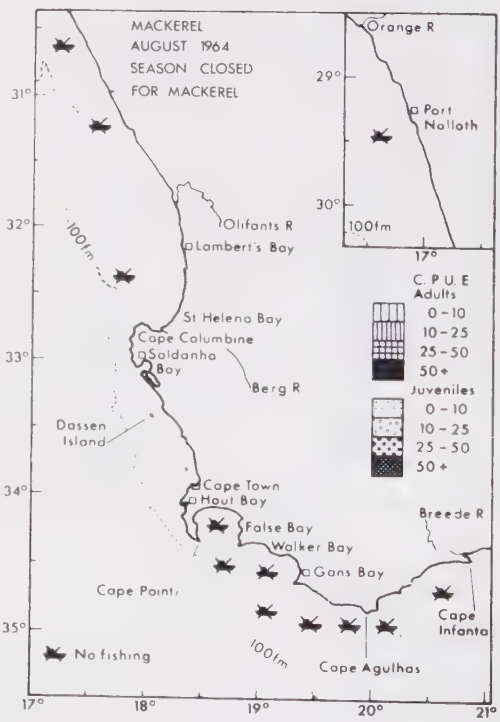
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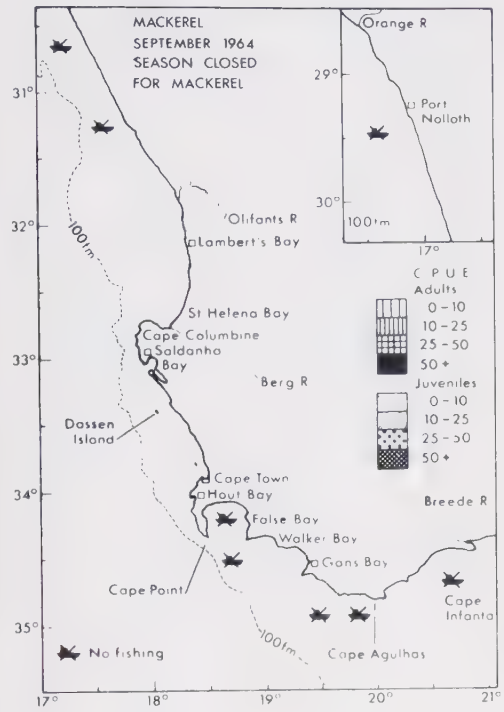
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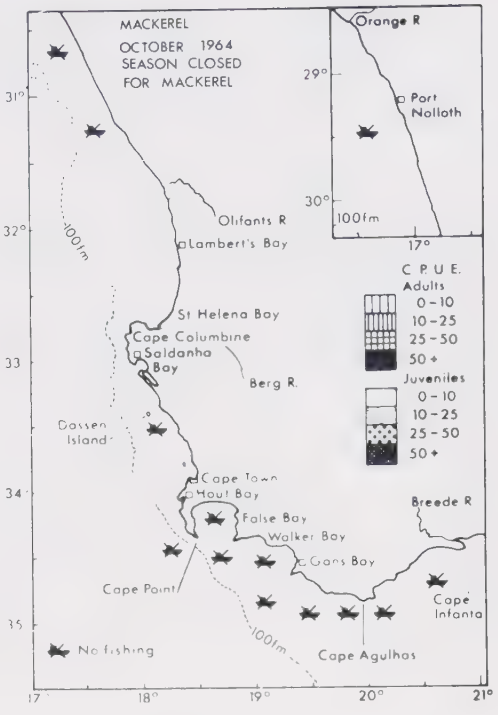
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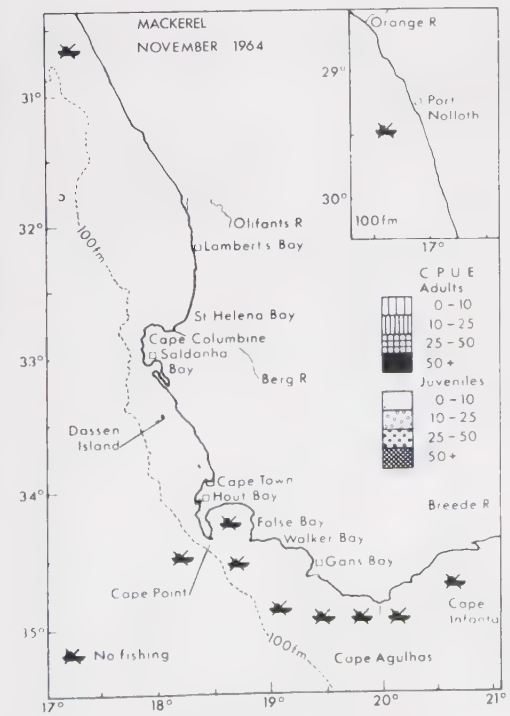
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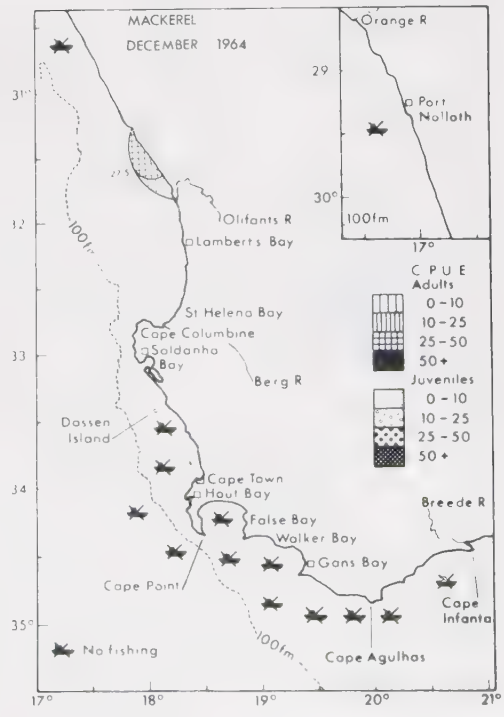
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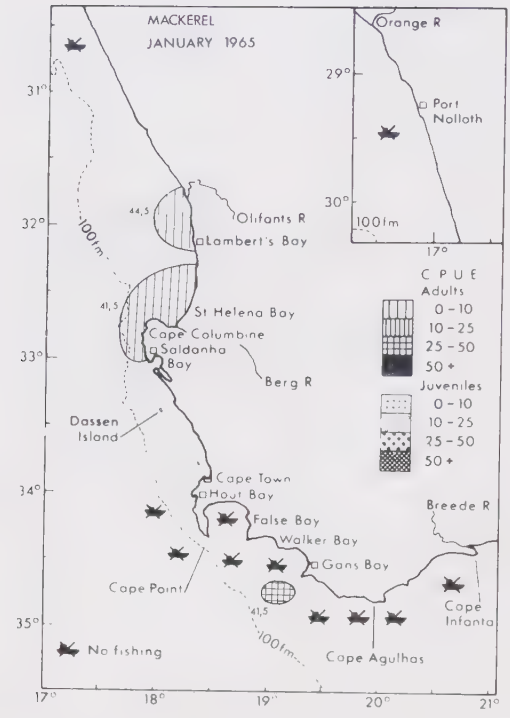
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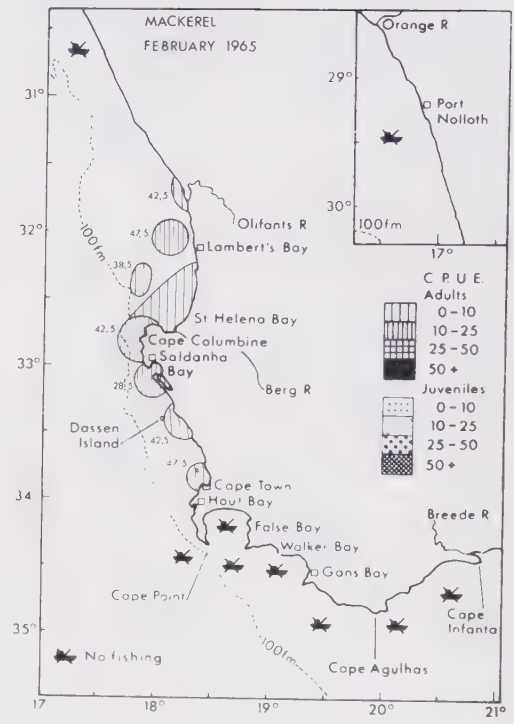
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Juveniles
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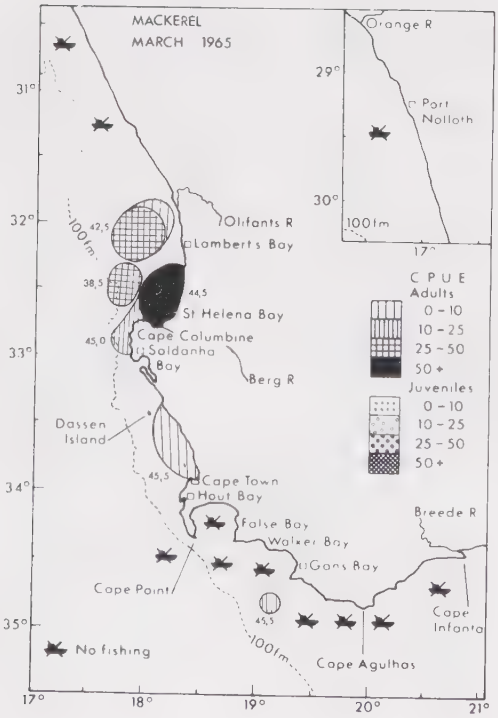
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St Helena Bay
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Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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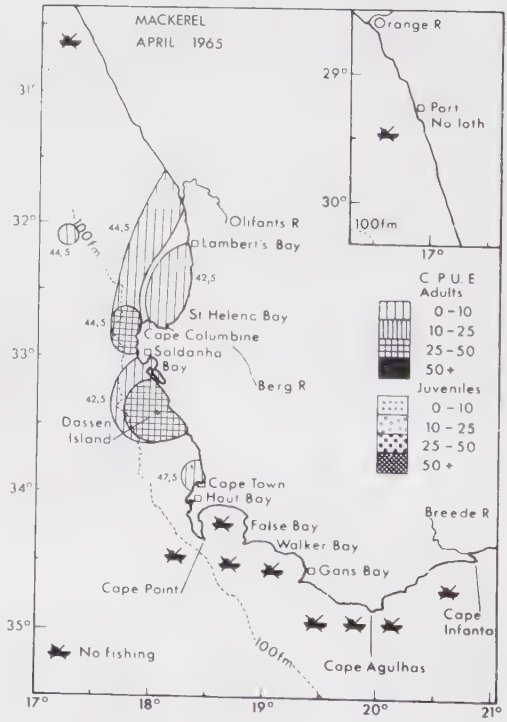
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Cape Town
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Gans Bay
Breede R
Cape Point
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Cape Agulhas
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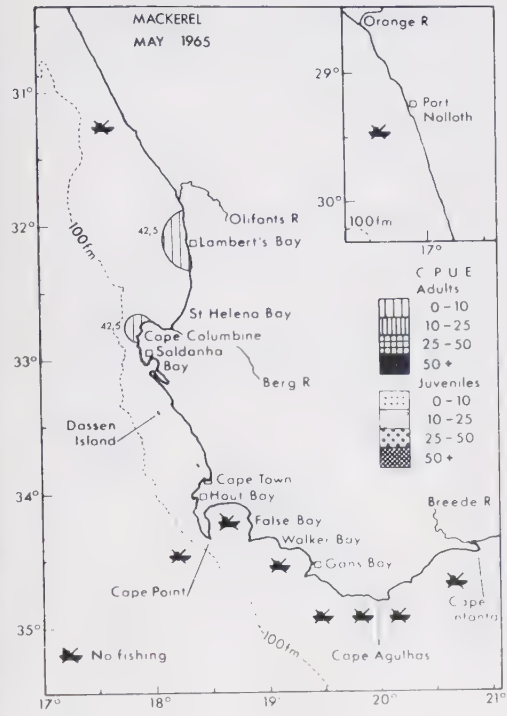
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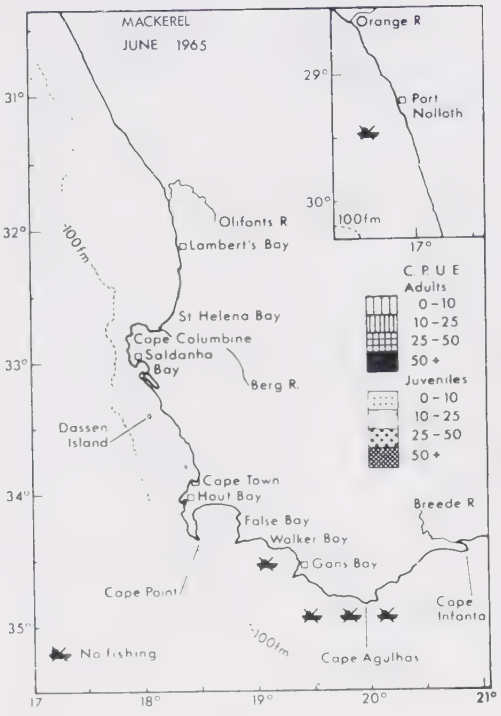
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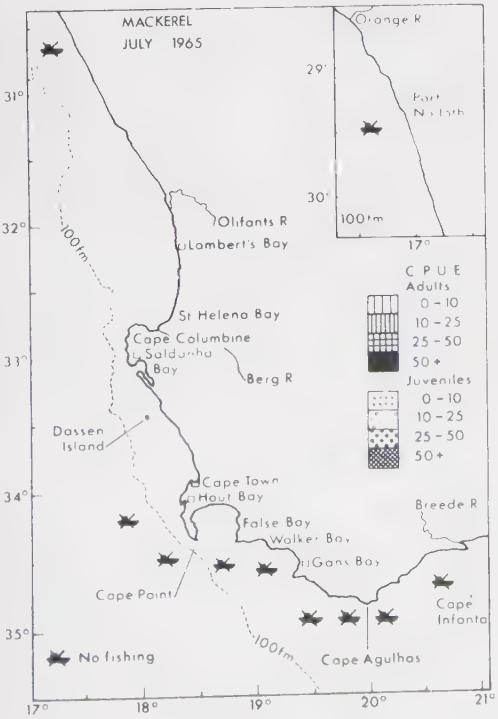
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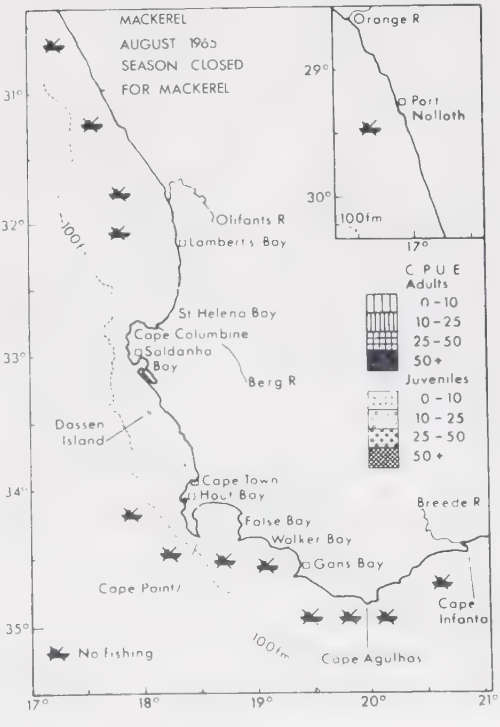
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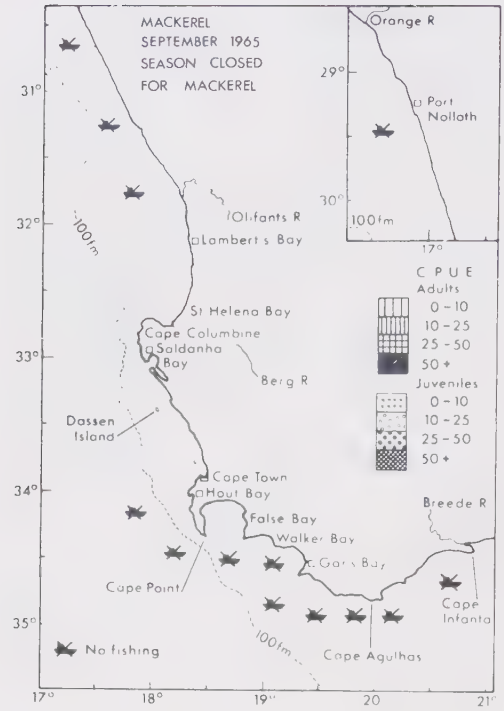
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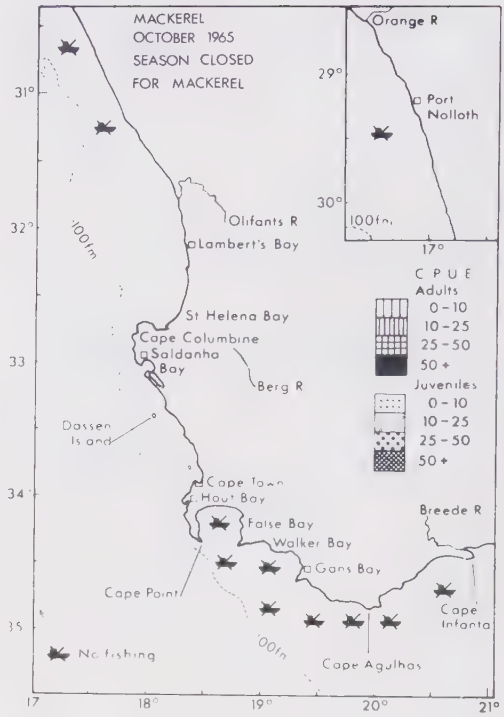
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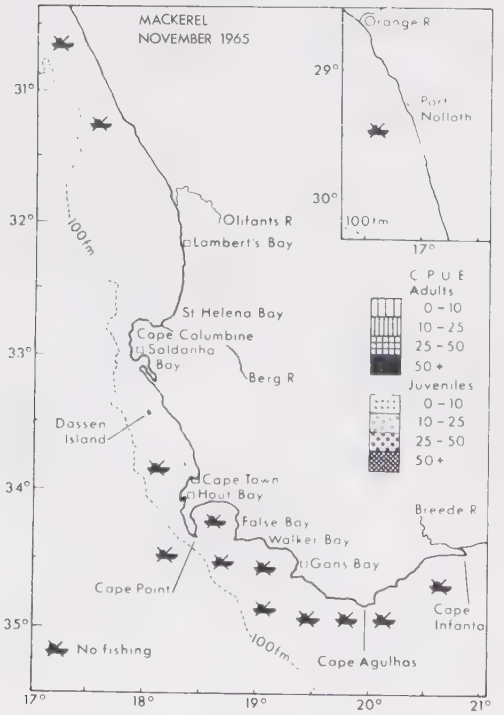
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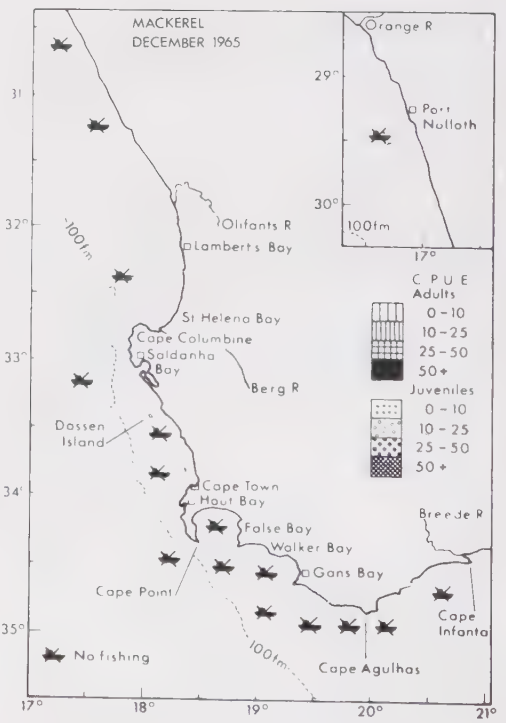
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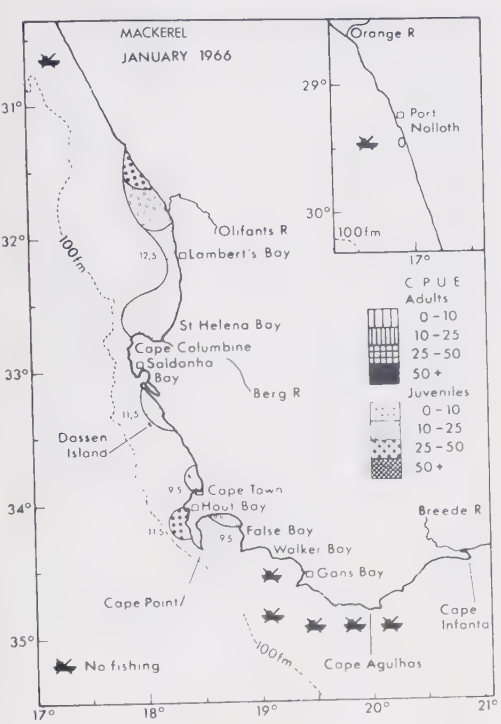
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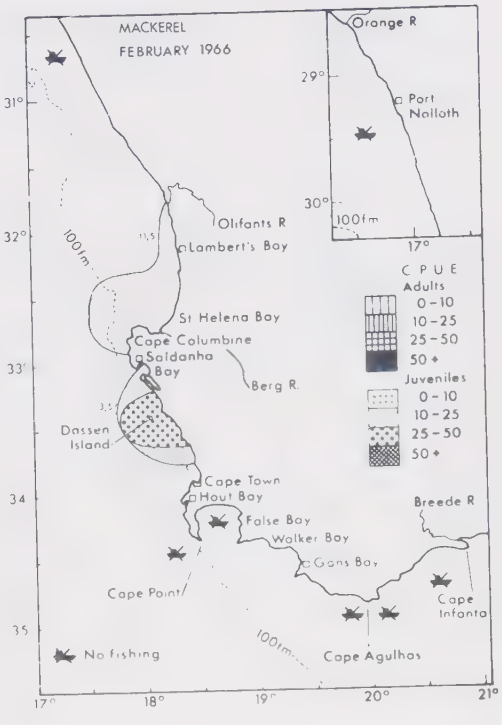
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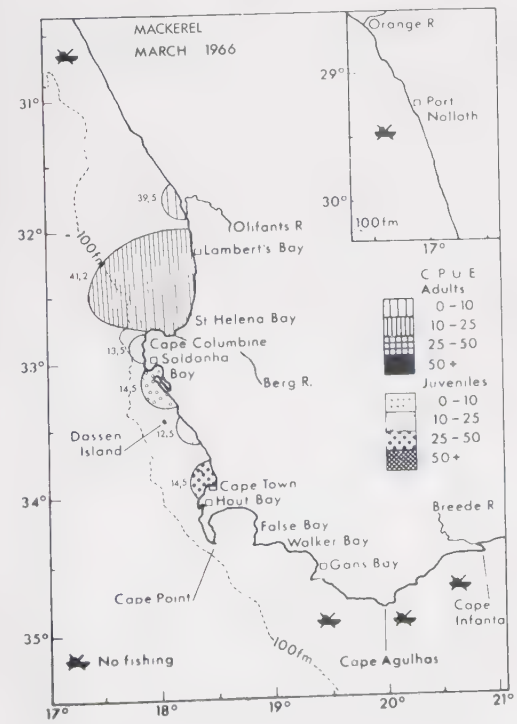
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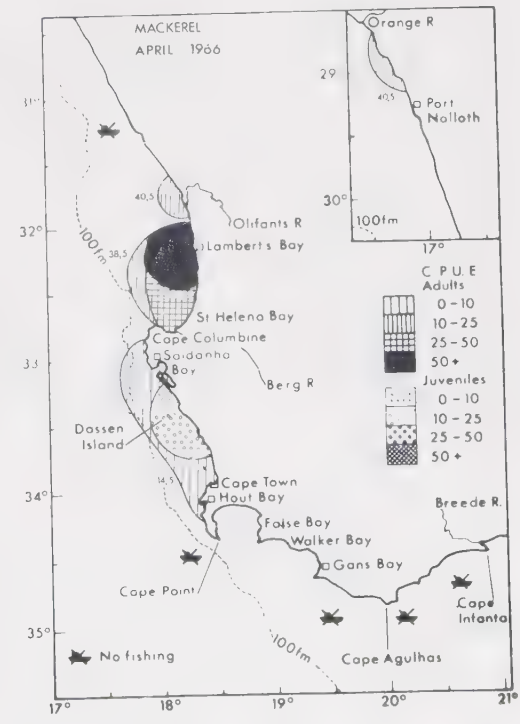
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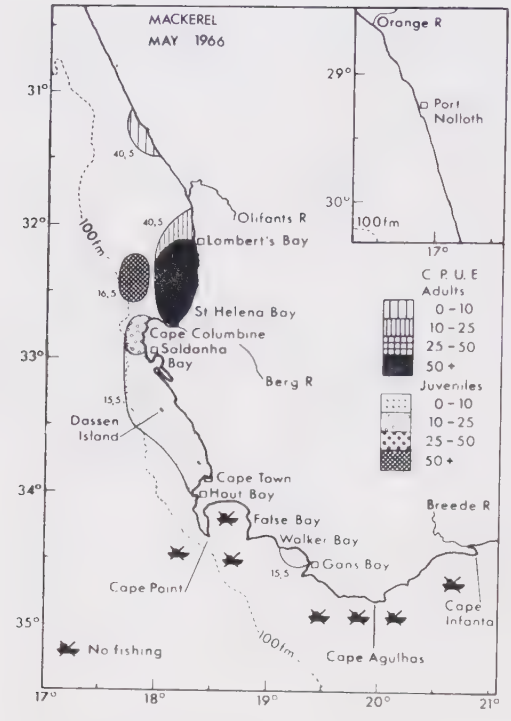
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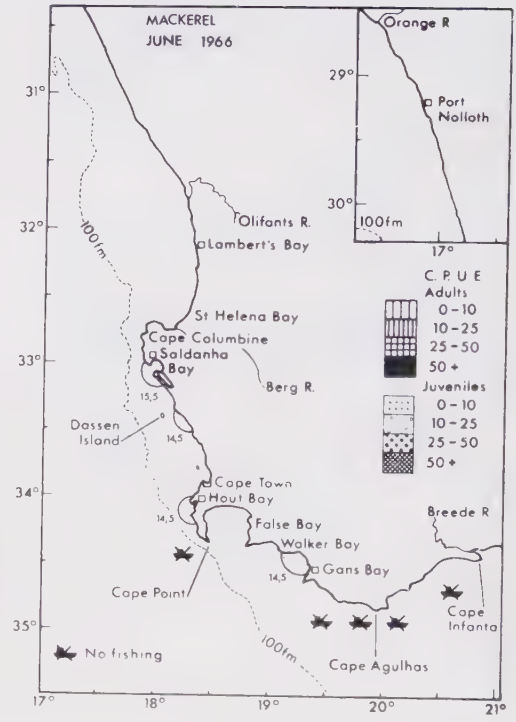
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Olifants R.
Lambert's Bay
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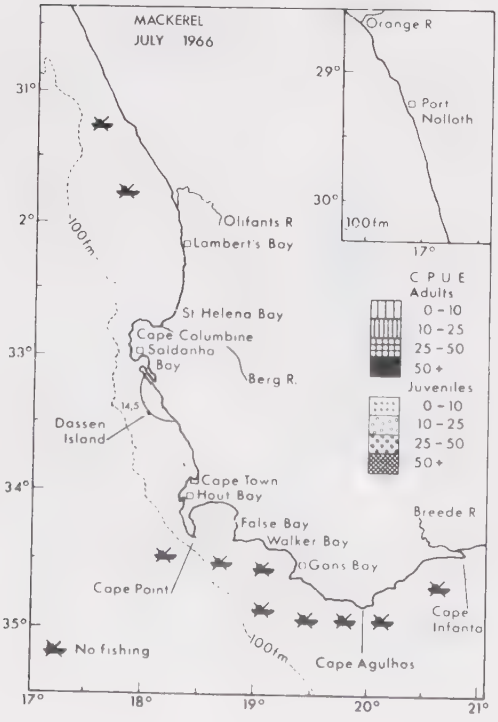
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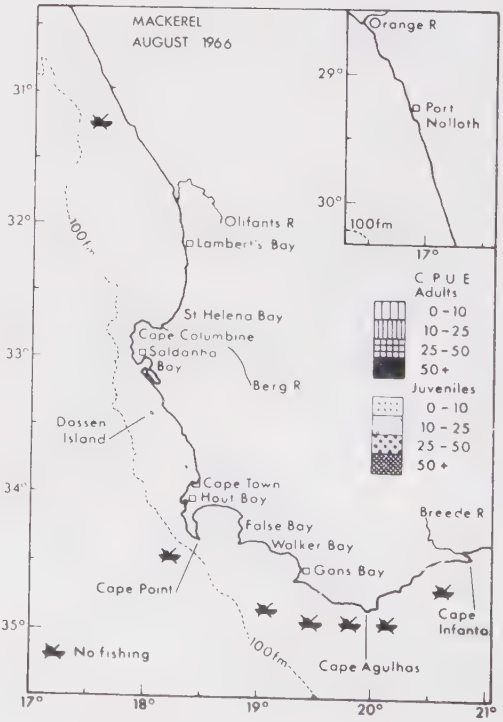
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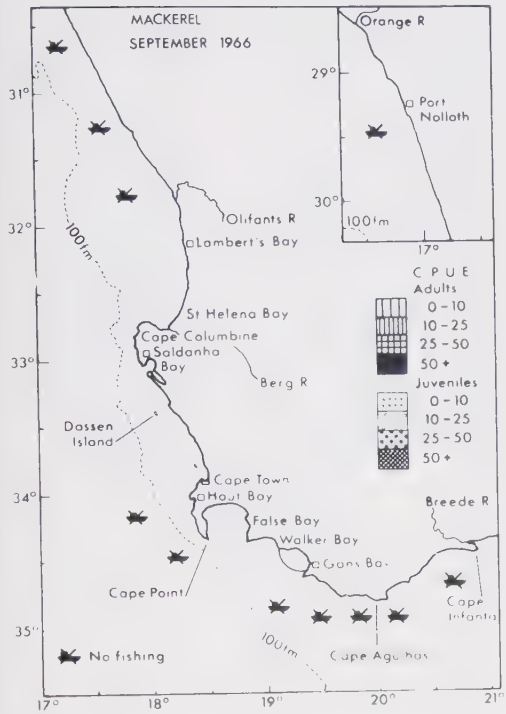
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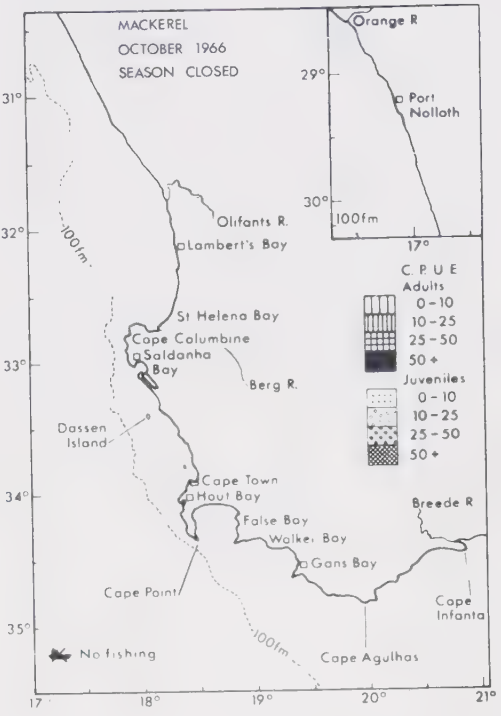
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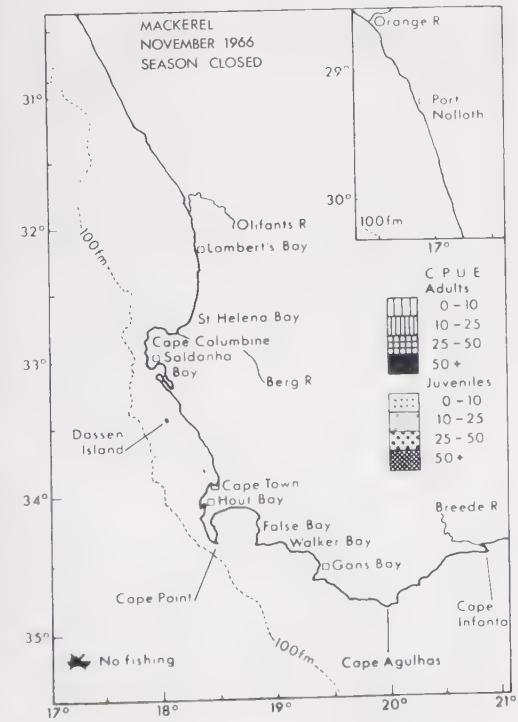
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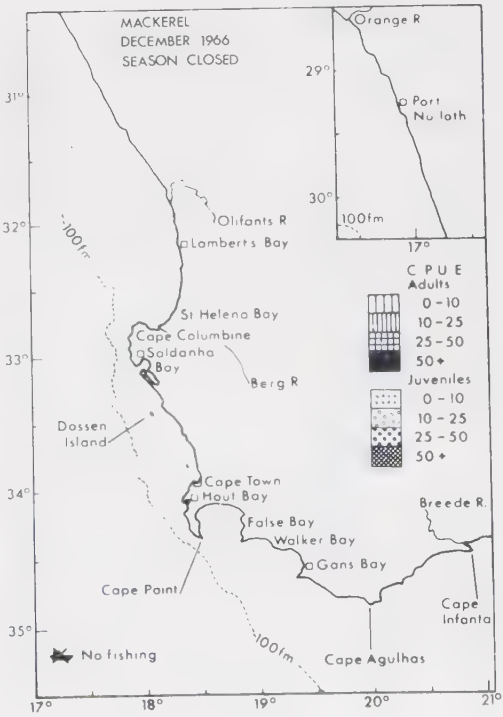
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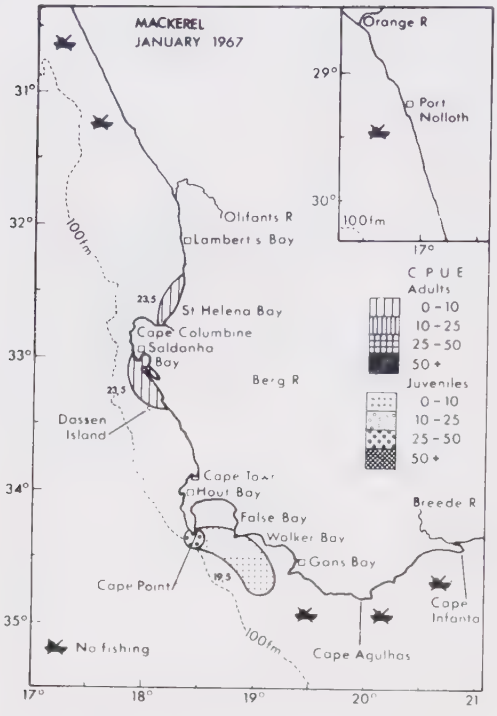
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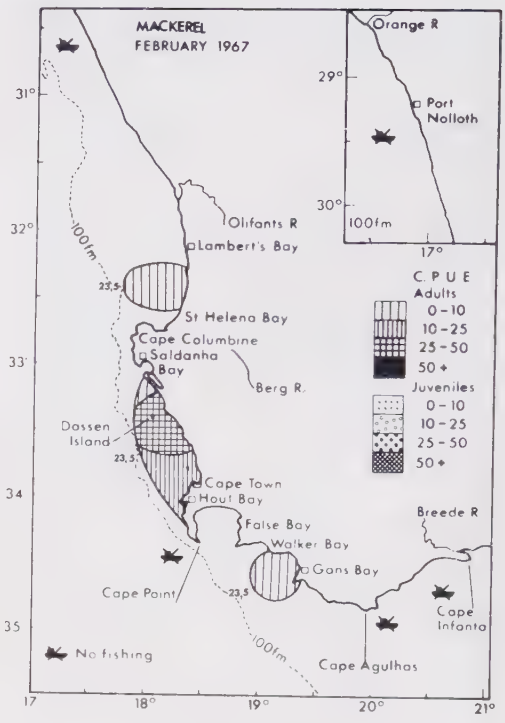
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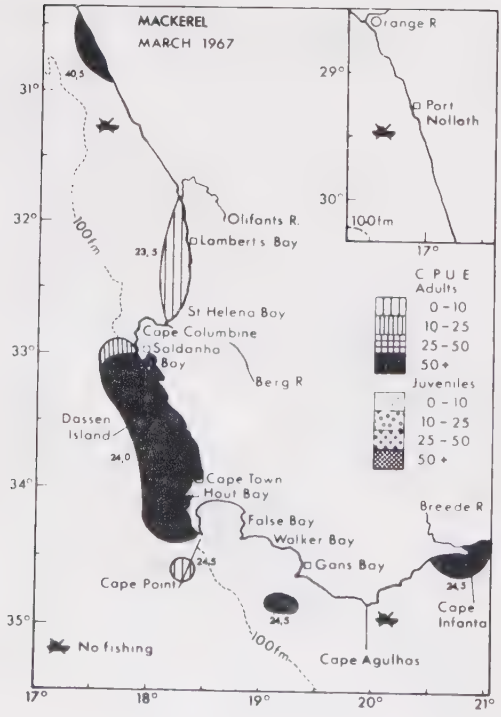
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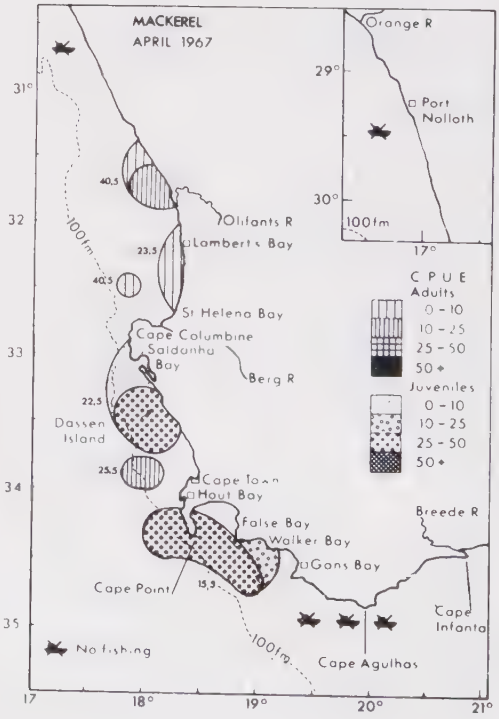
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Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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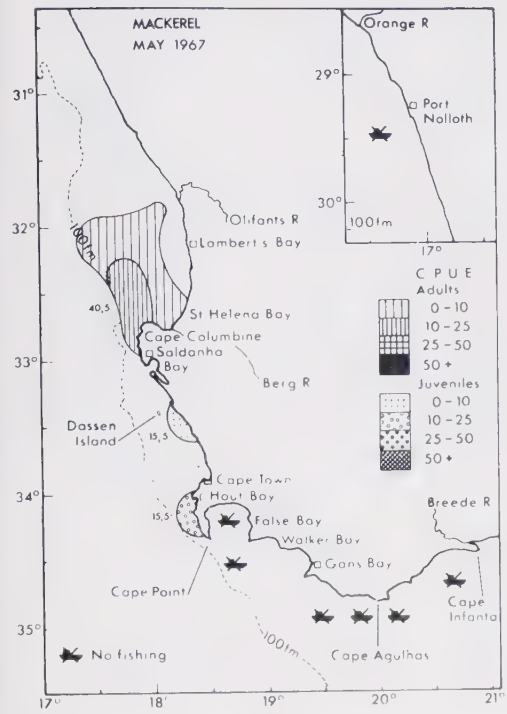
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No fishing
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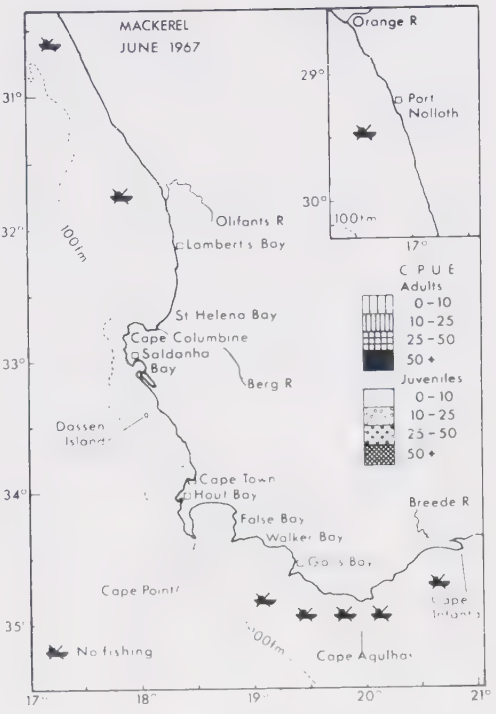
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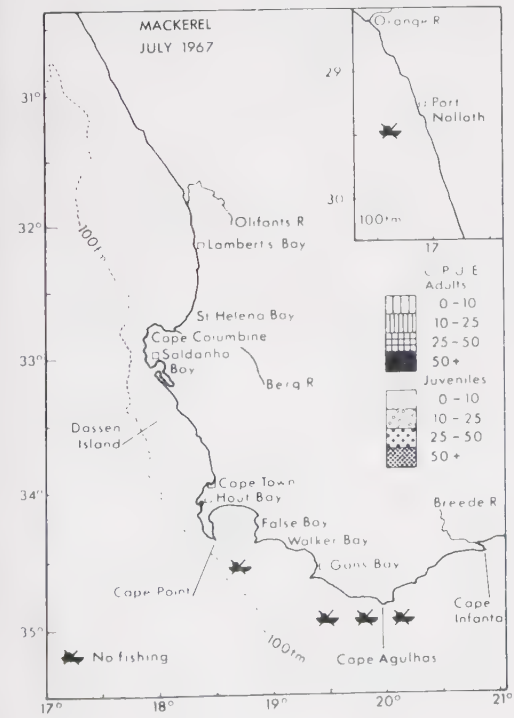
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Breede R
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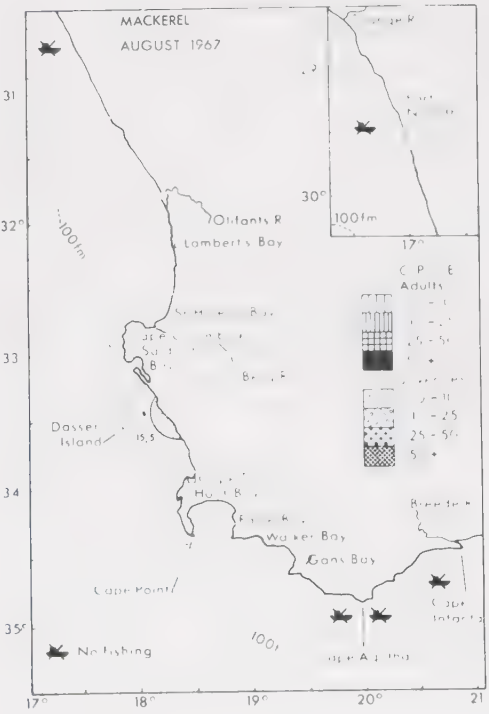
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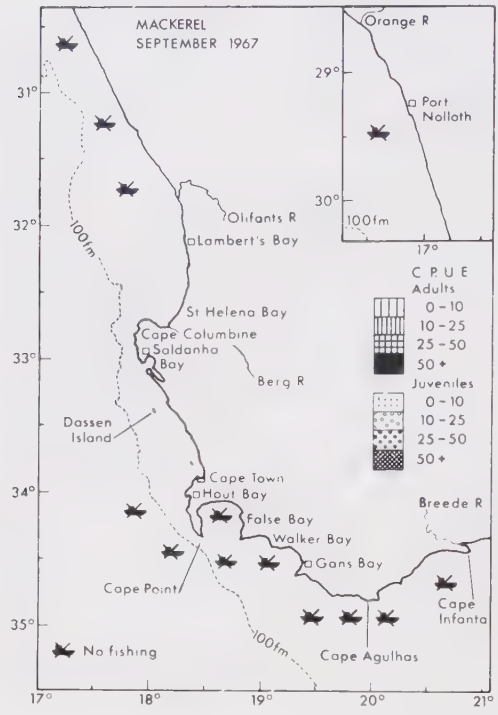
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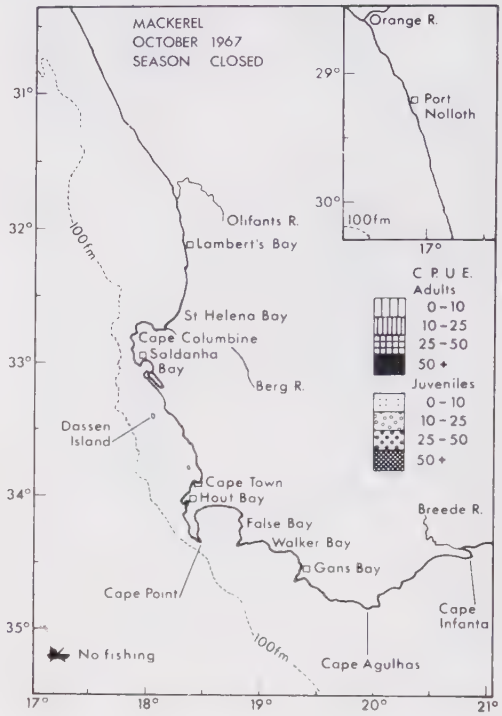
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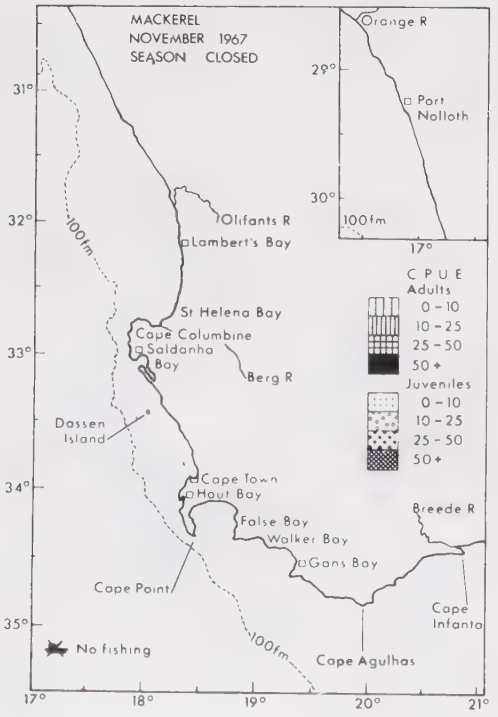
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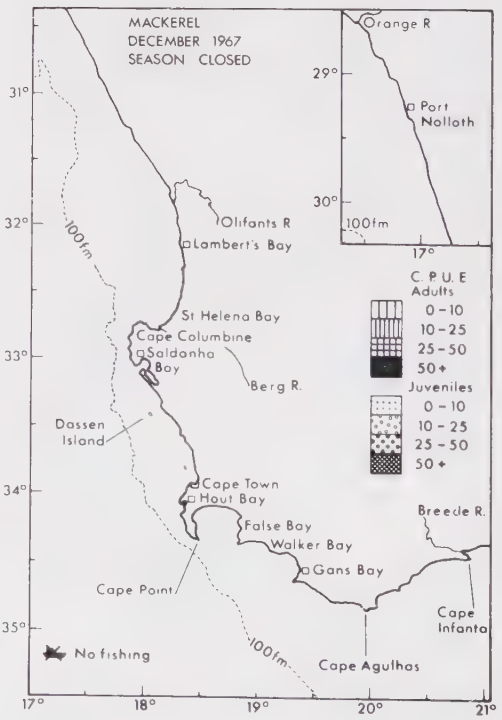
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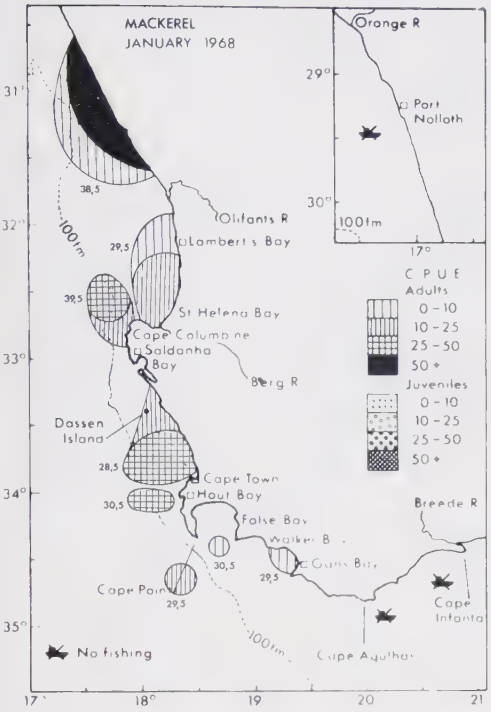
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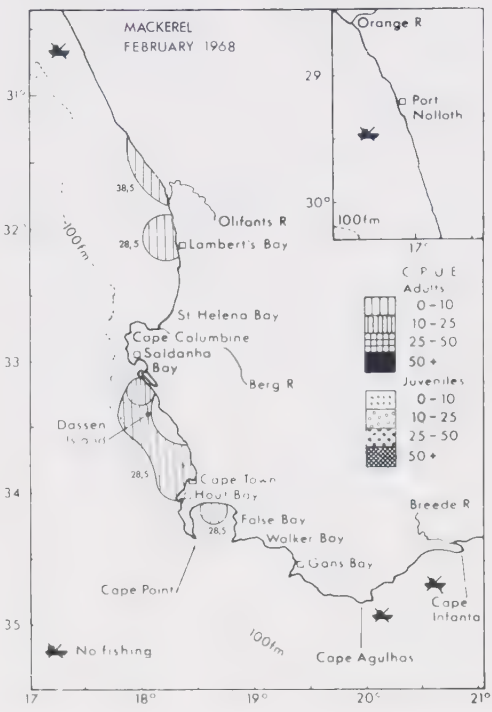
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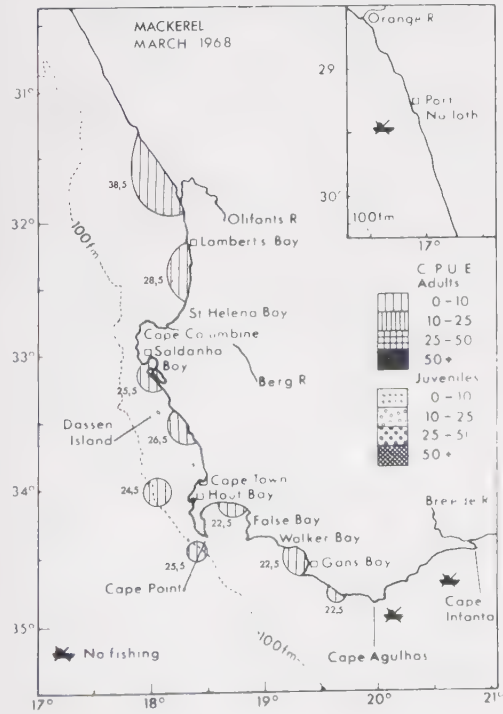
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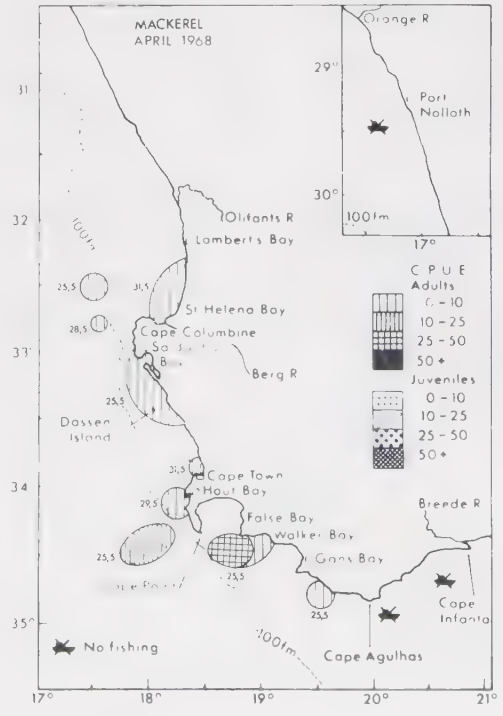
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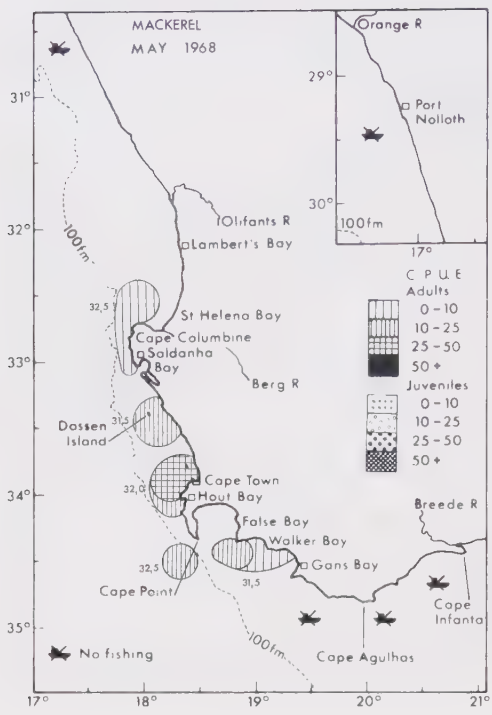
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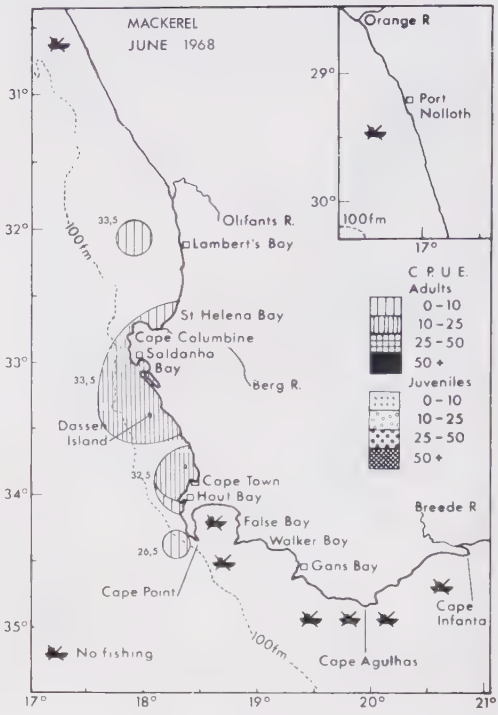
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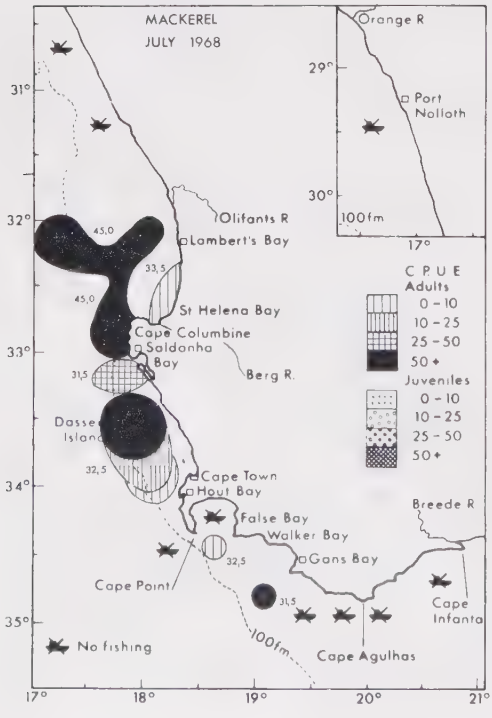
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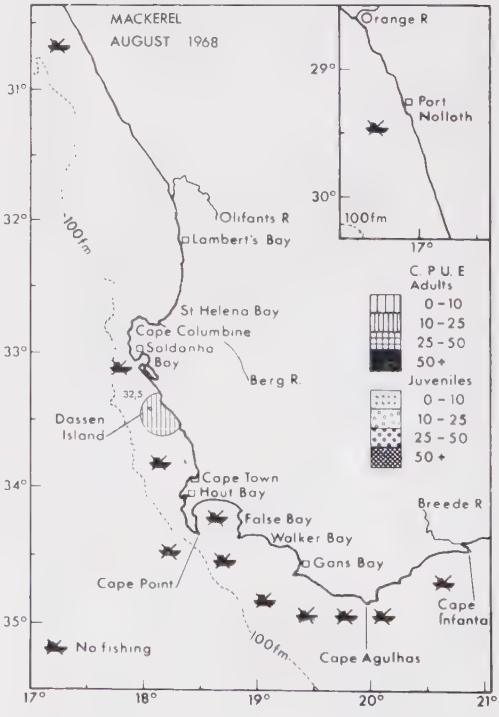
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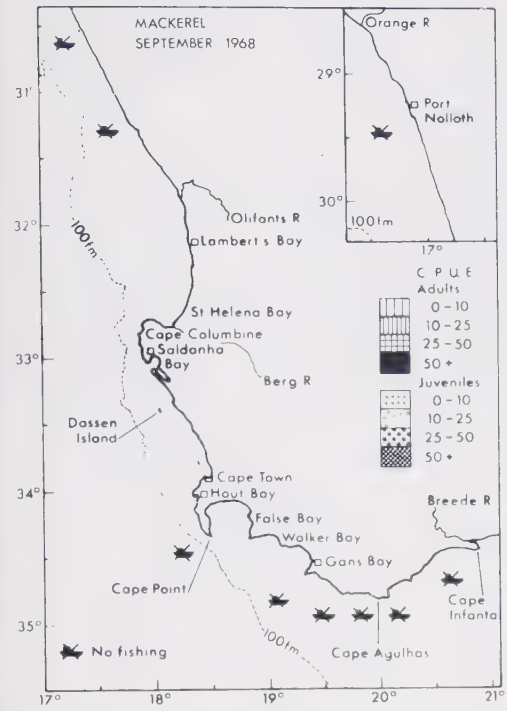
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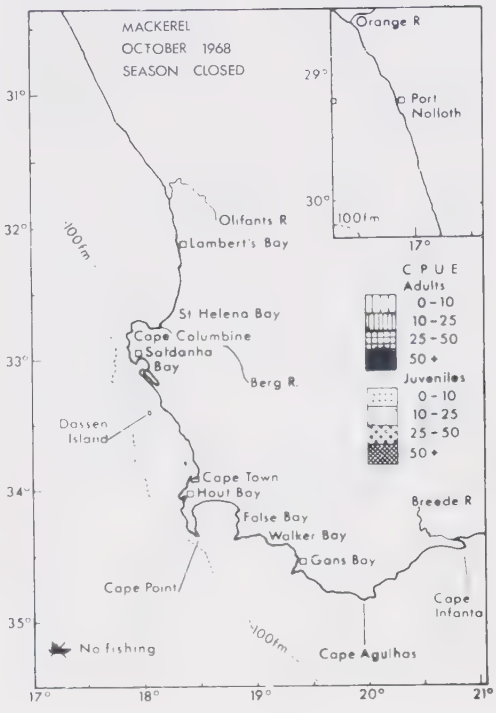
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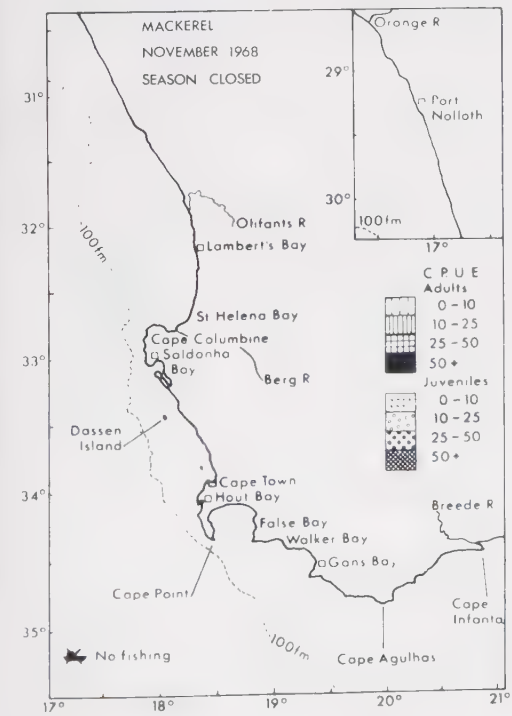
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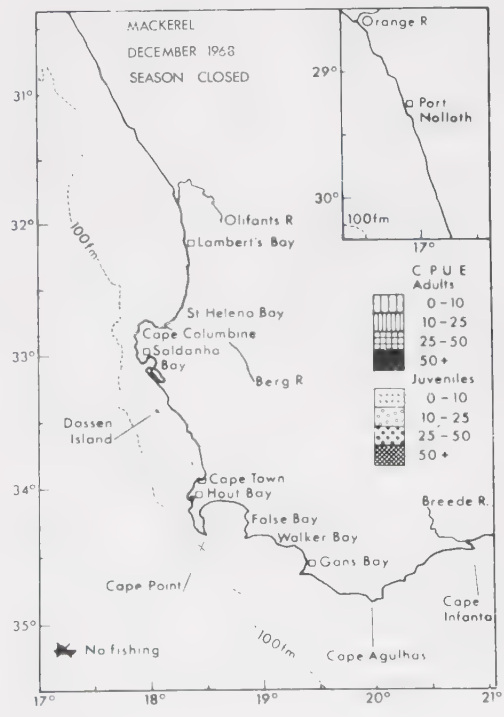
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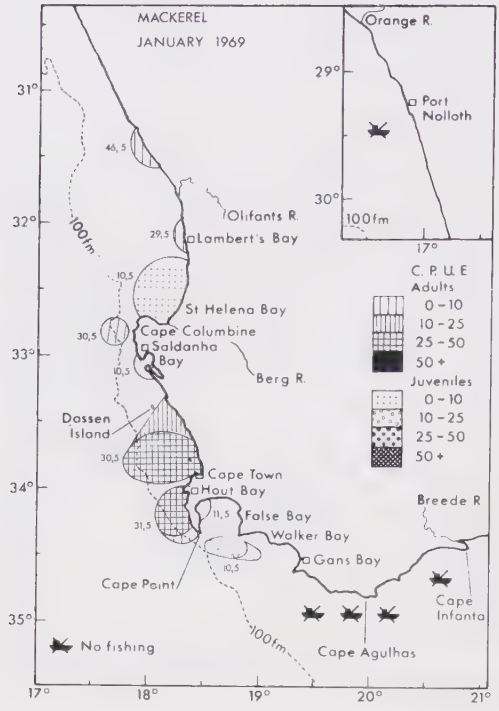
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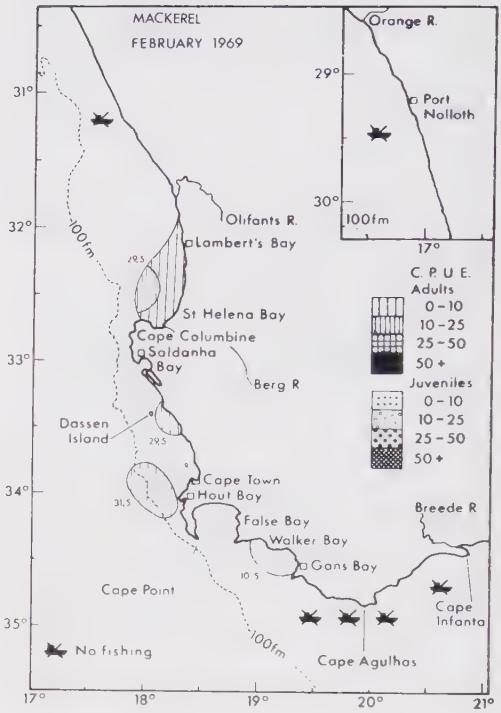
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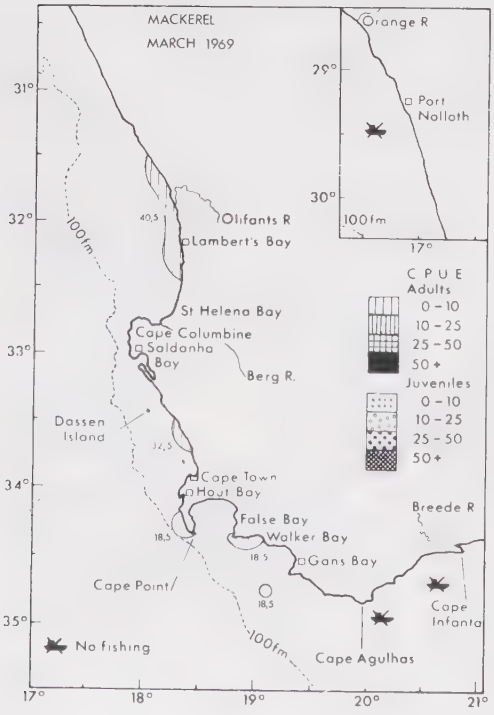
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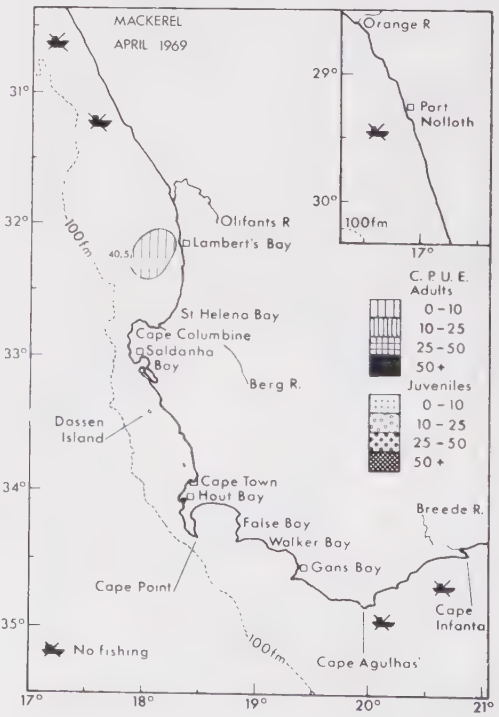
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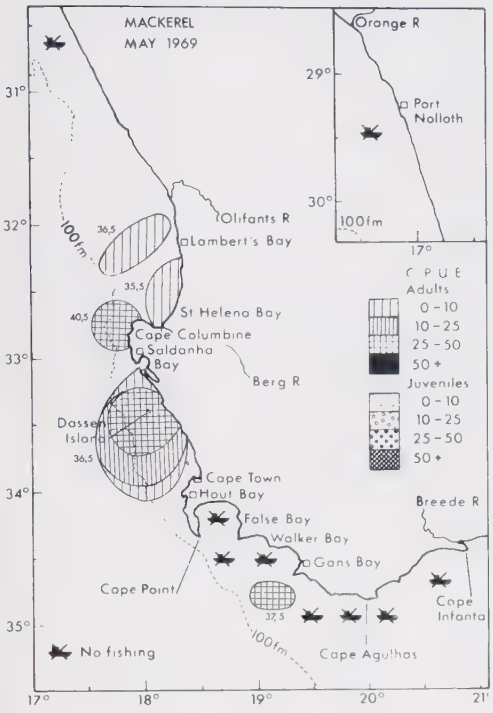
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MAY 1969
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
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Juveniles
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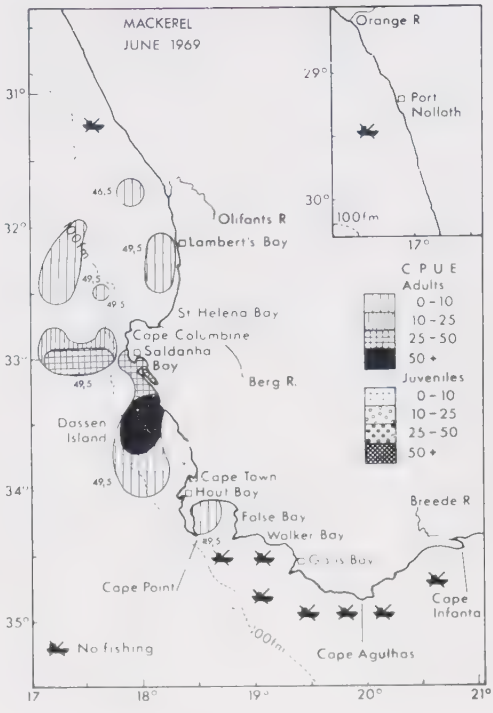
10 - 25
25 - 50
50 +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JUNE 1969
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Port Nolloth
100fm
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0 - 10
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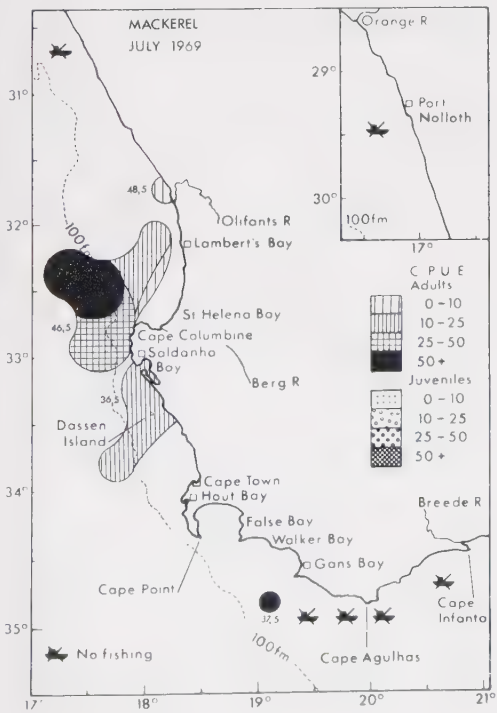
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +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JULY 1969
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Port Nolloth
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0 - 10
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Juveniles
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10 - 25
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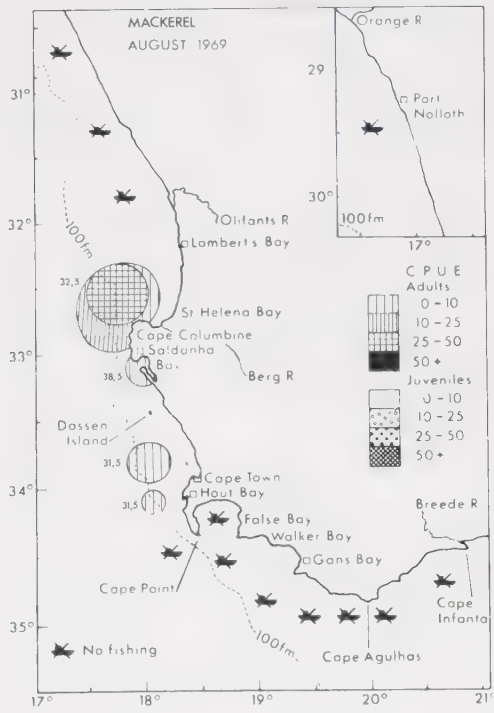
50 +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AUGUST 1969
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Port Nolloth
100fm
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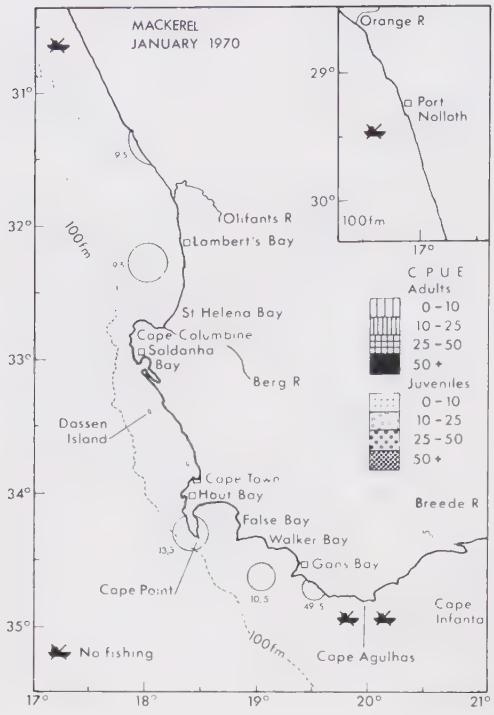
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
JANUARY 1970
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
34°
35°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
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18°
19°
20°
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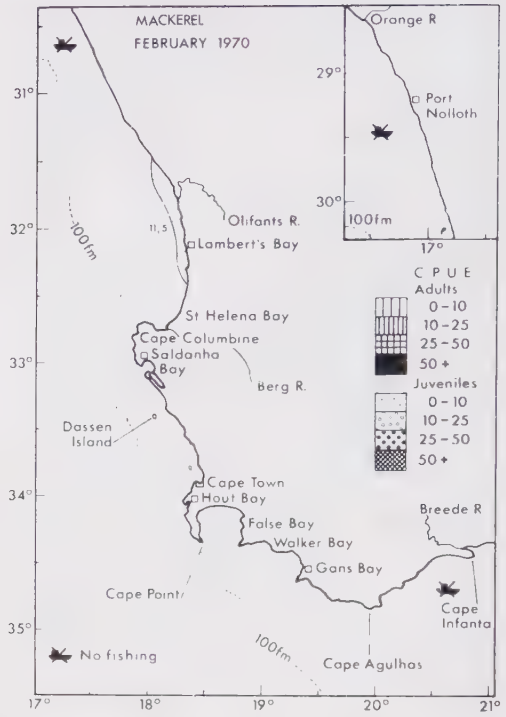
MACKEREL
FEBRUARY 1970
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
34°
35°
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
11,5
17°
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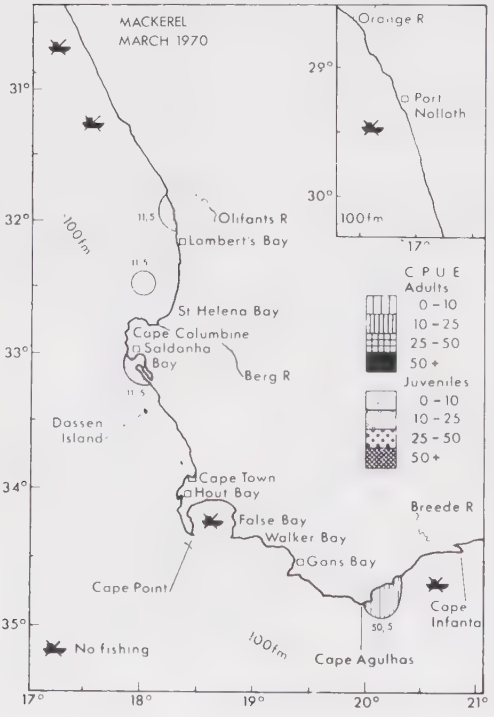
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MARCH 1970
Orange R
Port Nolloth
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100fm
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31°
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33°
34°
35°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
11,5
50,5
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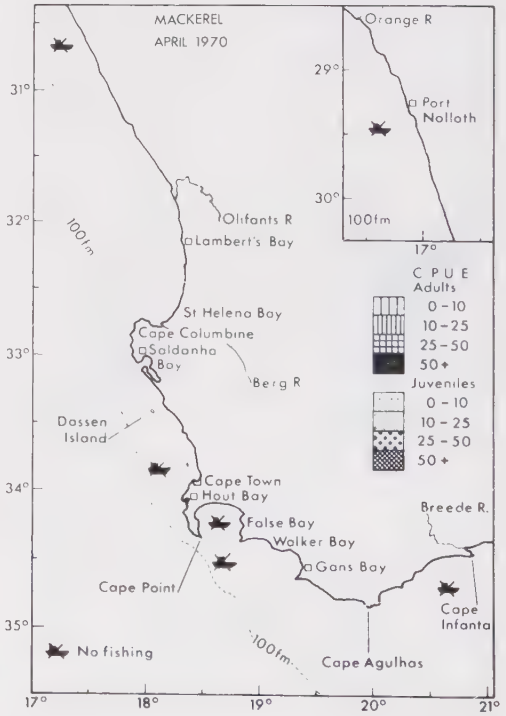
19°
20°
21°


MACKEREL
APRIL 1970
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Port Nolloth
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32°
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34°
35°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
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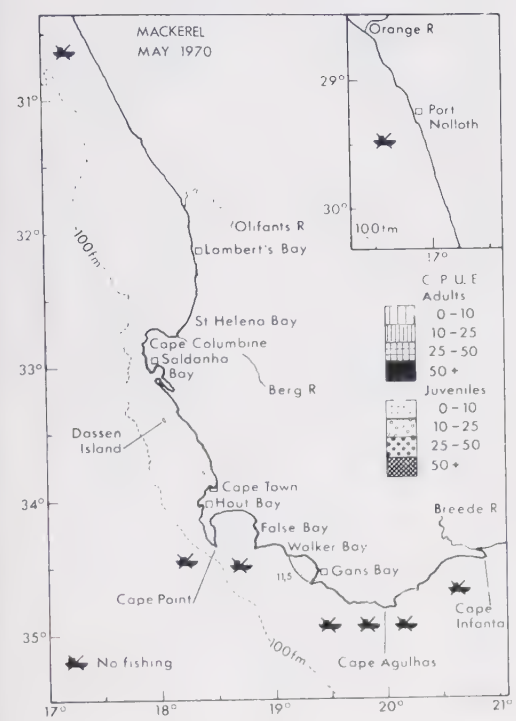
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MAY 1970
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Port Nolloth
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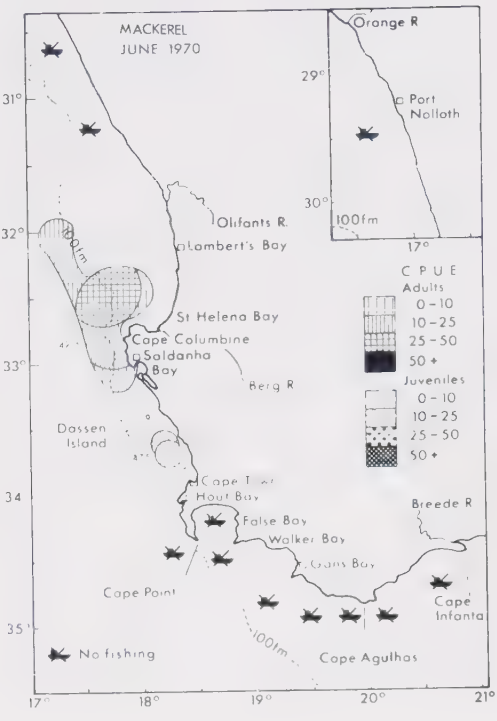
34°
35°
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
17°
18°
19°
20°
21°


MACKEREL
JUNE 1970
Orange R
Port Nolloth
29°
30°
100fm
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31°
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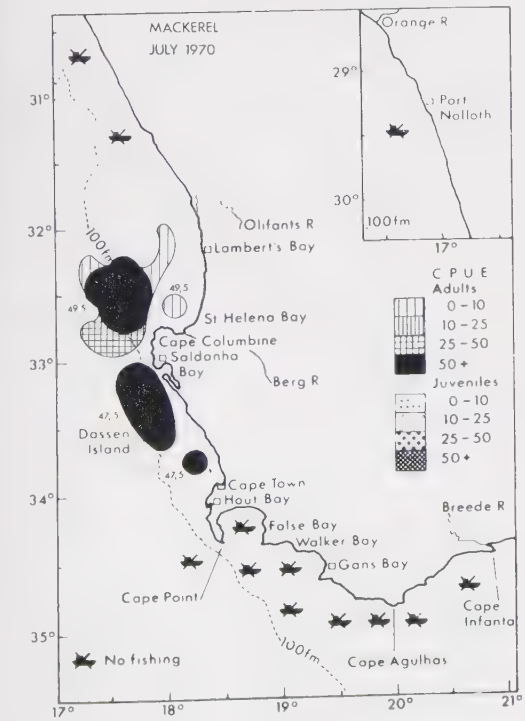
33°
34°
35°
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
17°
18°
19°
20°
21°


MACKEREL
JULY 1970
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Port Nolloth
29°
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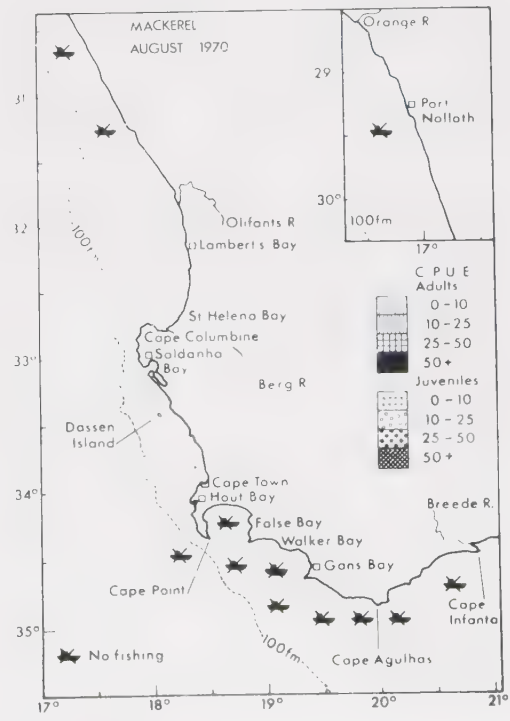
100fm
17°
31°
32°
33°
34°
35°
100fm
Olifants R
Lambert's Bay
49.5
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
47.5
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
17°
18°
19°
20°
21°


MACKEREL
AUGUST 1970
Orange R
Port Nolloth
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30°
100fm
17°
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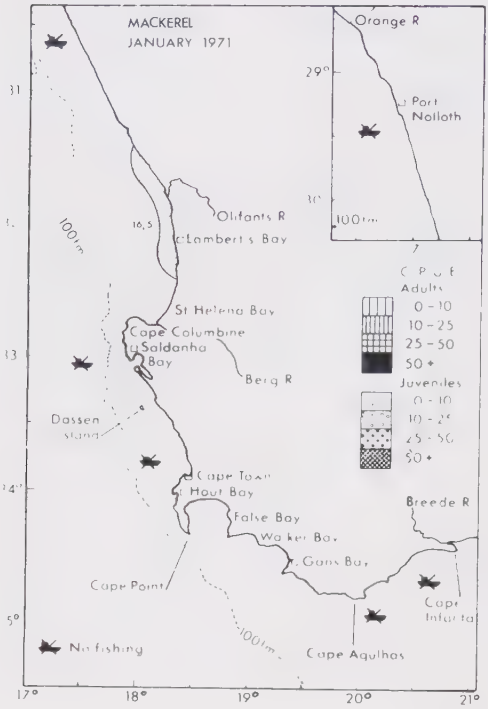
33°
34°
35°
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
17°
18°
19°
20°
21°


MACKEREL
JANUARY 1971
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
No fishing
C P U E
Adults
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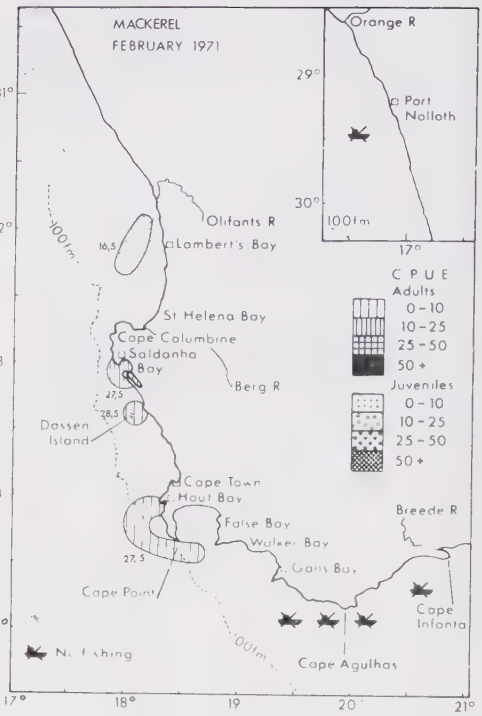
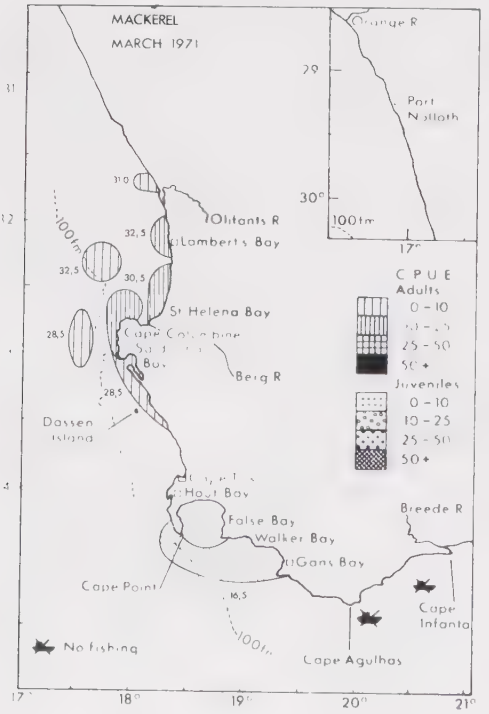
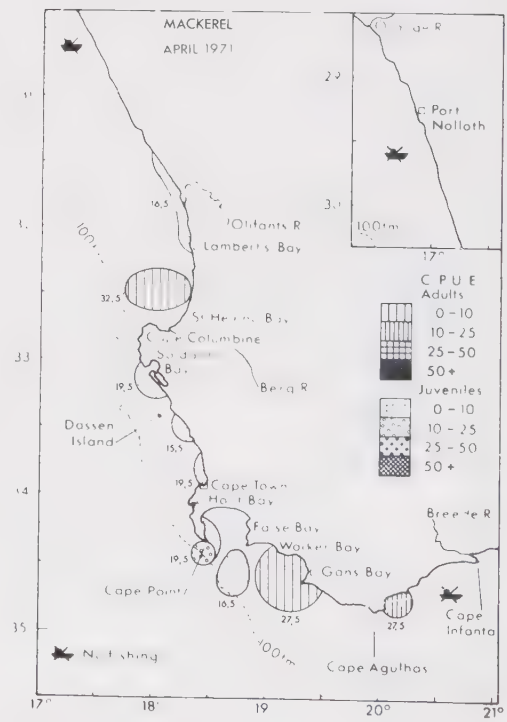
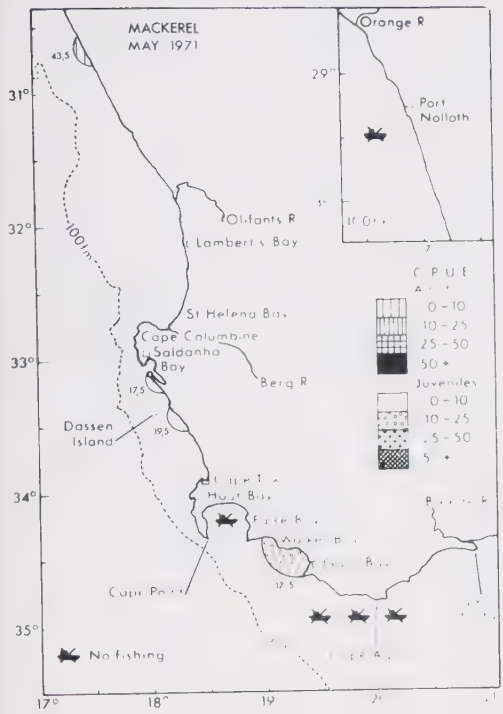
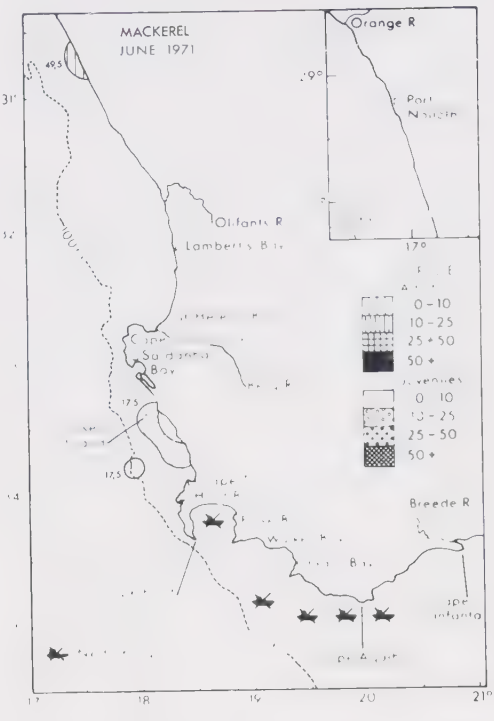
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +

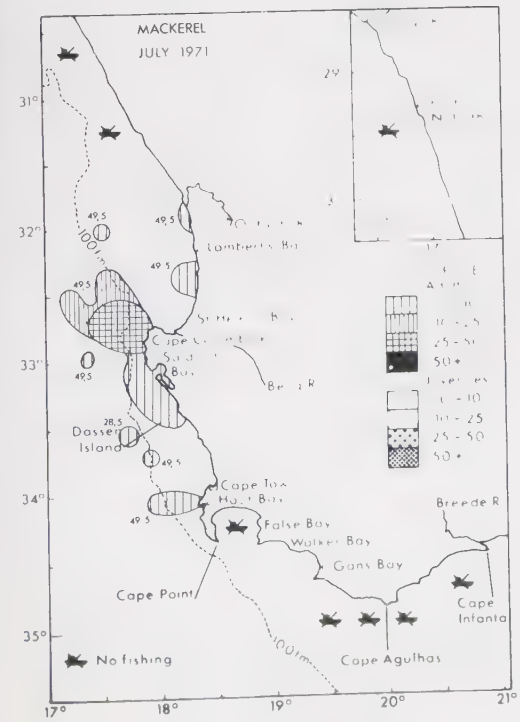

MACKEREL
FEBRUARY 1971
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +

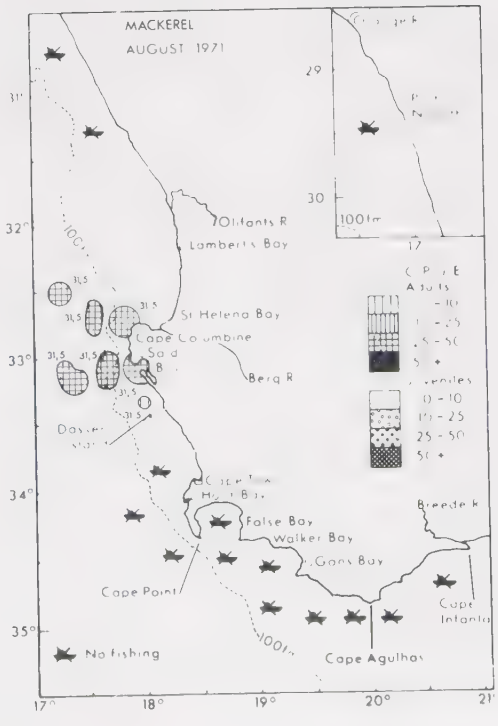

MACKEREL
MARCH 1971
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Berg R
Dassen Island
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
No fishing
C P U E
Adults
0 - 10
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +

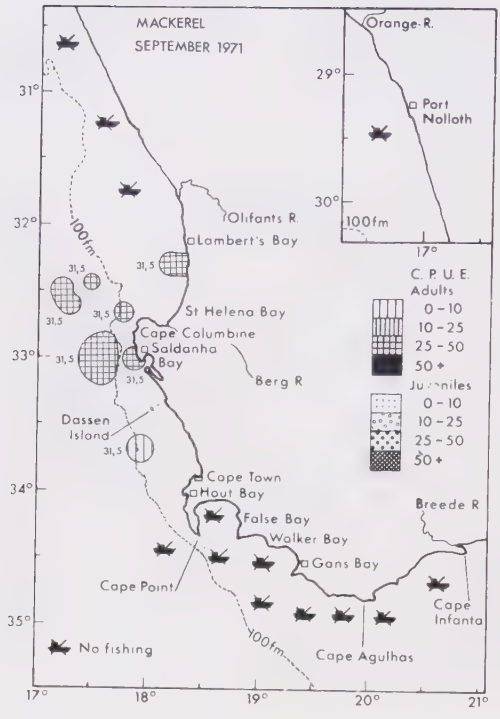

MACKEREL
APRIL 1971
Port Nolloth
Olifants R
Lambert's Bay
Berg R
Dassen Island
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
MAY 1971
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Point
No fishing
CPUE
Juveniles
0 - 10
10 - 25
25 - 50
50 +
100fm


MACKEREL
JUNE 1971
Orange R
Olifants R
Lambert's Bay
Breede R
0 - 10
10 - 25
25 + 50
50 +
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
JULY 1971
Lambert's Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Cape Point
Breede R
Cape Infanta
Cape Agulhas
No fishing
100fm


MACKEREL
AUGUST 1971
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Berg R
Cape Point
False Bay
Walker Bay
Gans Bay
Breede R
Cape Infanta
Cape Agulhas
No fishing
100fm
Adults
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
SEPTEMBER 1971
Orange R.
Port Nolloth
100fm
C. P. U. E.
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
31,5
29°
30°
31°
32°
33°
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35°
17°
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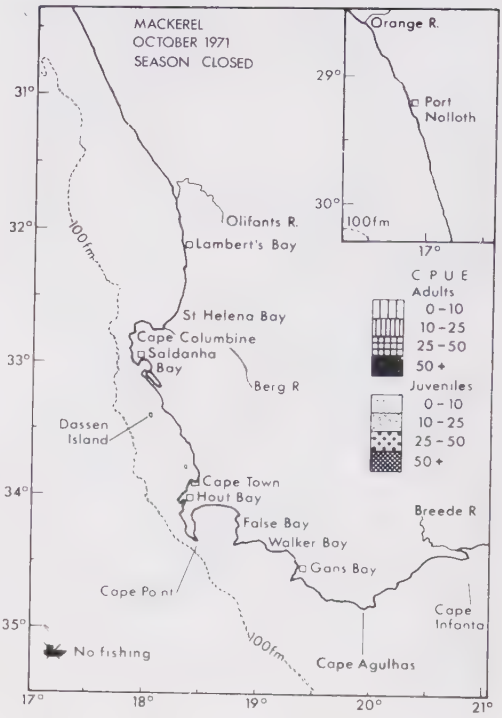
21°


MACKEREL
OCTOBER 1971
SEASON CLOSED
Orange R.
Port Nolloth
100fm
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
29°
30°
31°
32°
33°
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35°
17°
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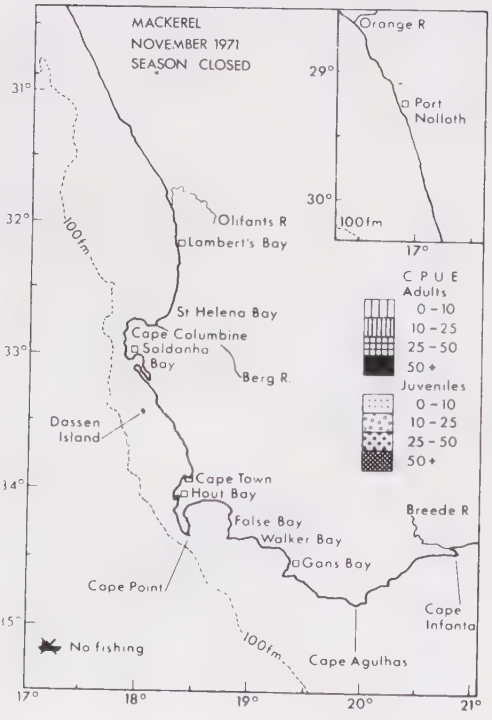
20°
21°


MACKEREL
NOVEMBER 1971
SEASON CLOSED
Orange R
Port Nolloth
100fm
C P U E
Adults
0 – 10
10 – 25
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50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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30°
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35°
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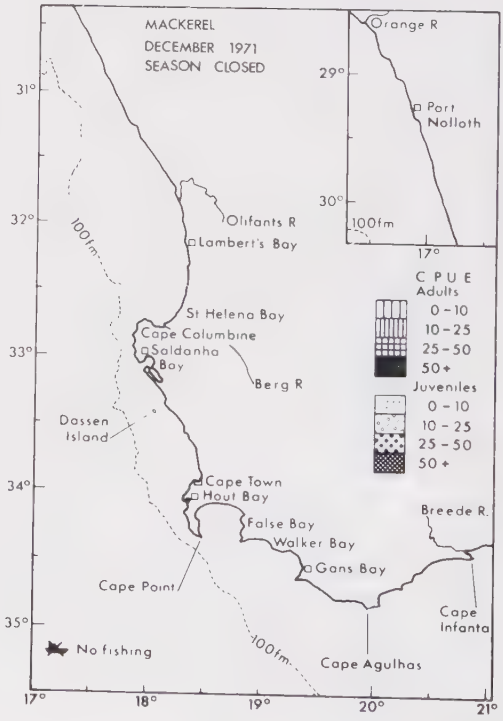
20°
21°


MACKEREL
DECEMBER 1971
SEASON CLOSED
Orange R
Port Nolloth
100fm
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
29°
30°
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32°
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35°
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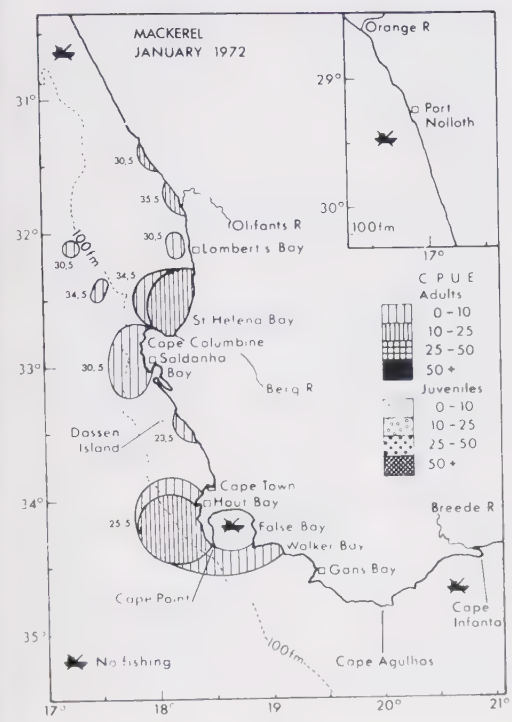
21°


MACKEREL
JANUARY 1972
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
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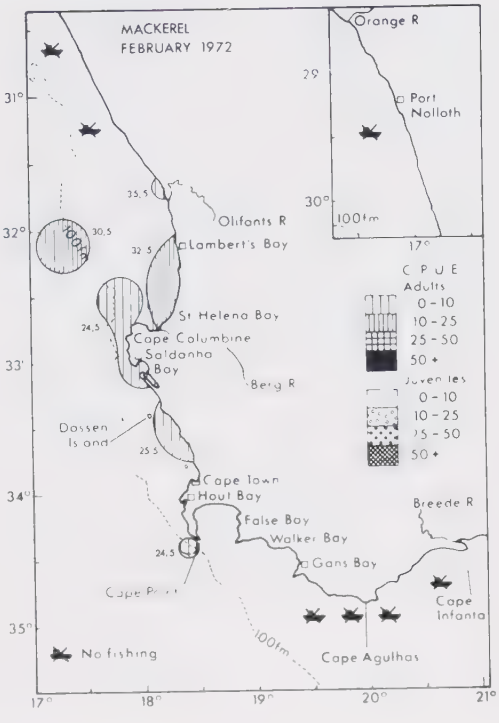
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
FEBRUARY 1972
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
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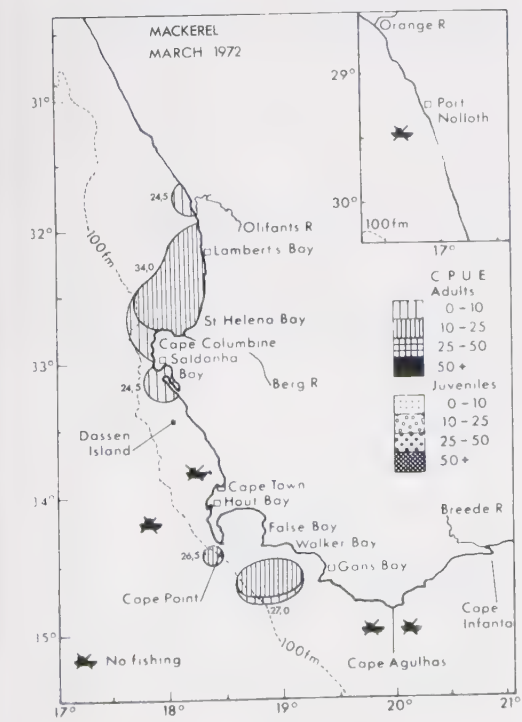
10 - 25
25 - 50
50 +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MARCH 1972
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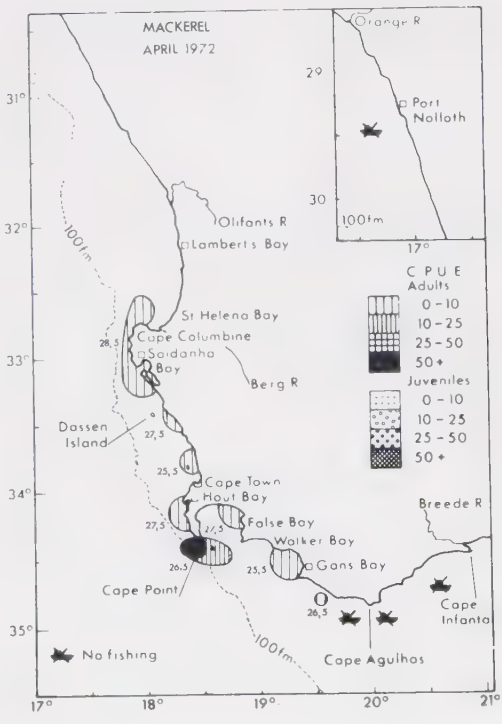
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
APRIL 1972
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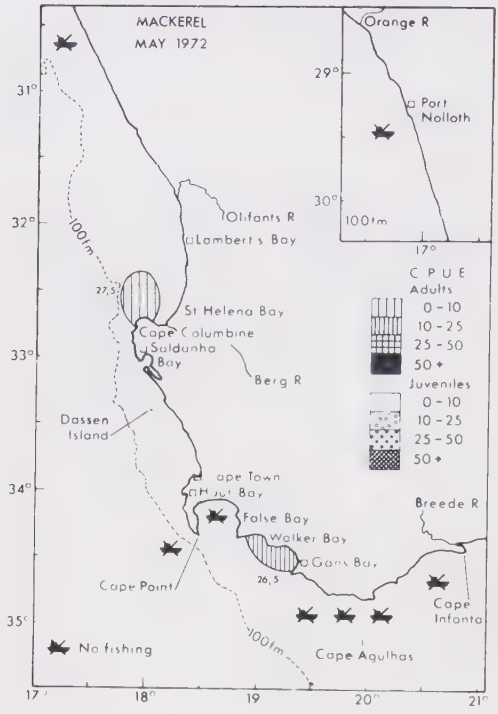
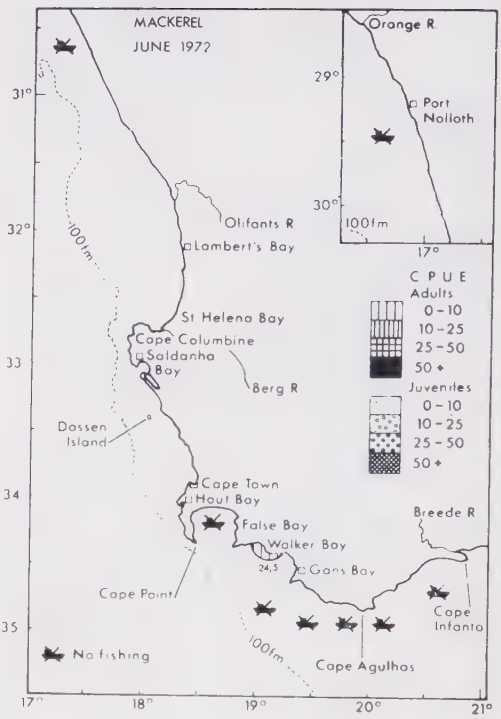
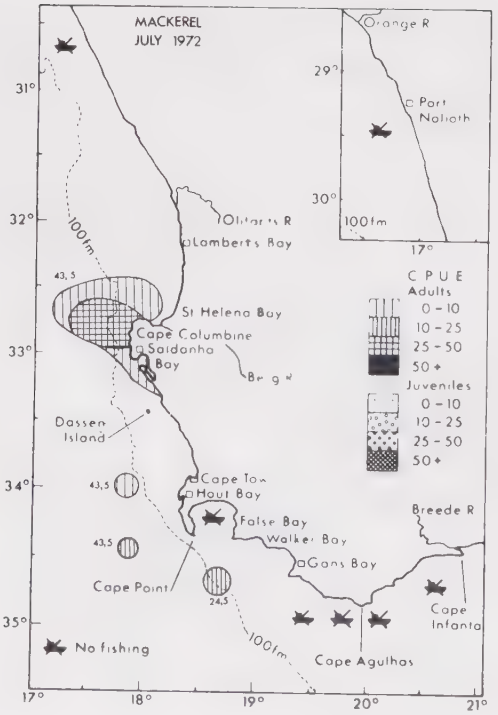
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
MAY 1972
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
34°
35°
Olifants R
Lambert's Bay
27,5
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
26,5
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
17°
18°
19°
20°
21°


MACKEREL
JUNE 1972
Orange R.
Port Nolloth
29°
30°
100fm
17°
31°
32°
33
34
35
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
24,5
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
17°
18°
19°
20°
21°


MACKEREL
JULY 1972
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
34°
35°
Olifants R
Lambert's Bay
43,5
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
43,5
Cape Town
Hout Bay
False Bay
Walker Bay
43,5
Gans Bay
Breede R
Cape Point
24,5
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
17°
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19°
20°
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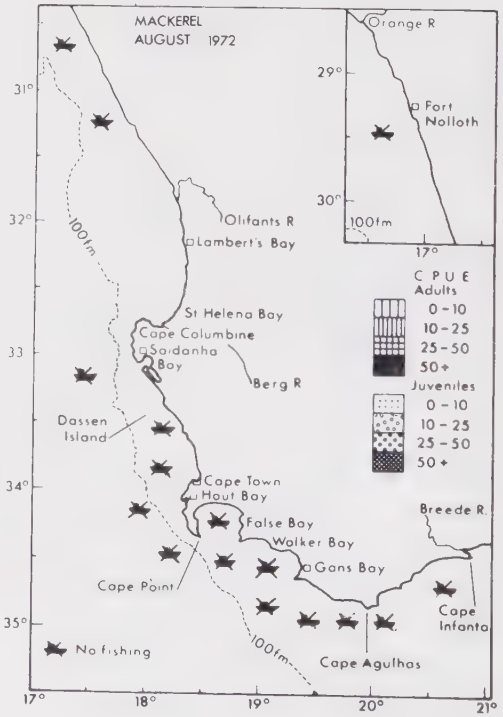
MACKEREL
AUGUST 1972
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
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34°
35°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0 - 10
10 - 25
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50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
17°
18°
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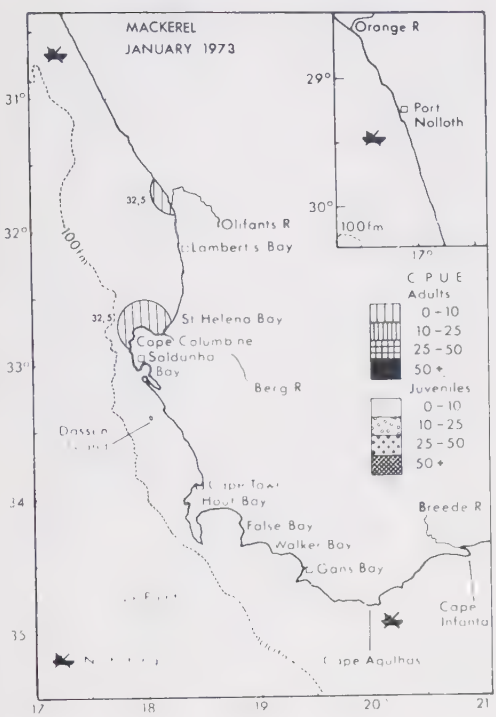
MACKEREL
JANUARY 1973
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
34°
35°
32,5
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Infanta
Cape Agulhas
100fm
CPUE
Adults
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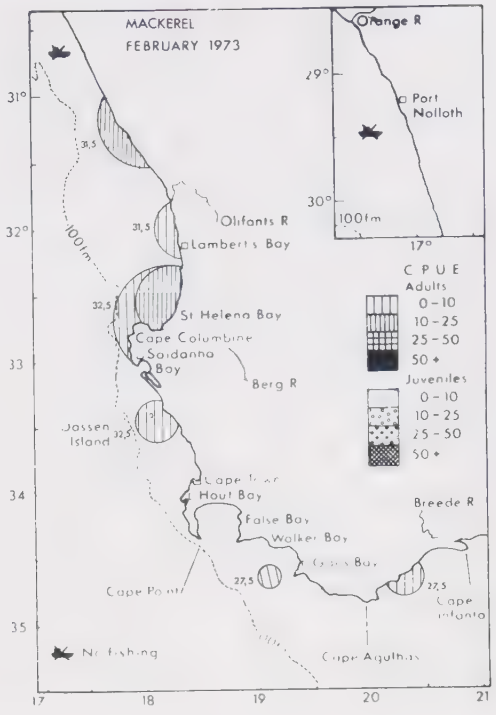
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
17
18
19
20
21


MACKEREL
FEBRUARY 1973
Orange R
Port Nolloth
29°
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100fm
17°
31°
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31,5
32,5
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Hout Bay
False Bay
Walker Bay
Breede R
27,5
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
CPUE
Adults
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10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
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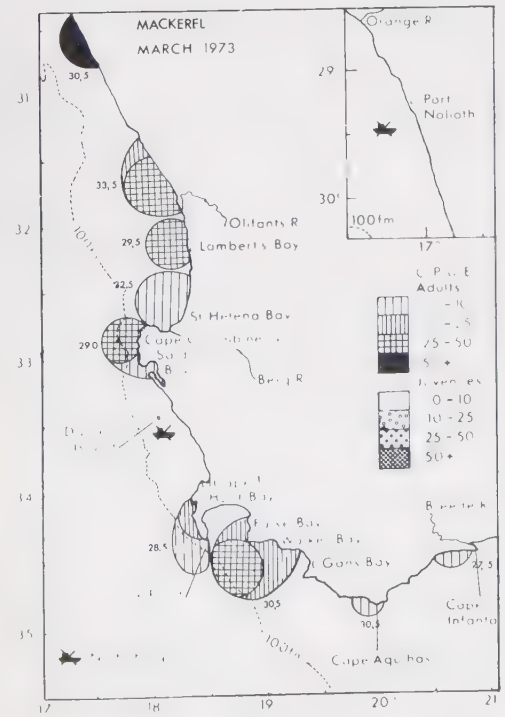
MACKEREL
MARCH 1973
Orange R
Port Nolloth
29
30°
100fm
17°
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33,5
29,5
22,5
29,0
28,5
Olifants R
Lambert's Bay
St Helena Bay
Berg R
Gans Bay
Cape Infanta
Cape Agulhas
100fm
CPUE
Adults
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
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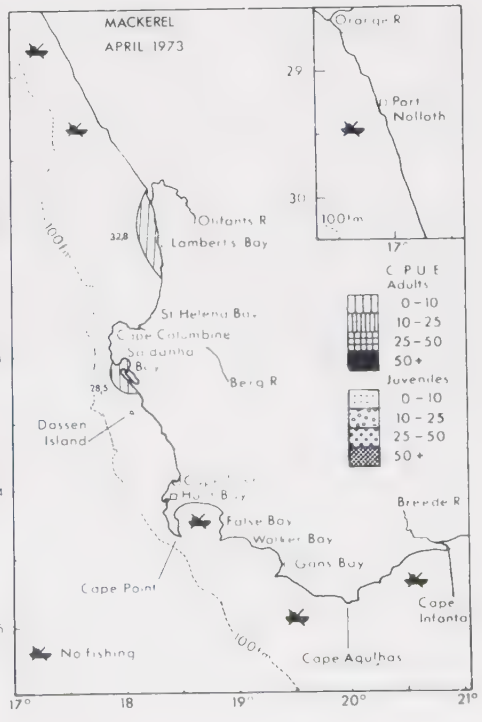
MACKEREL
APRIL 1973
Orange R
Port Nolloth
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30
100fm
17°
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32,8
28,5
Olifants R
Lambert's Bay
Berg R
Dassen Island
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
CPUE
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
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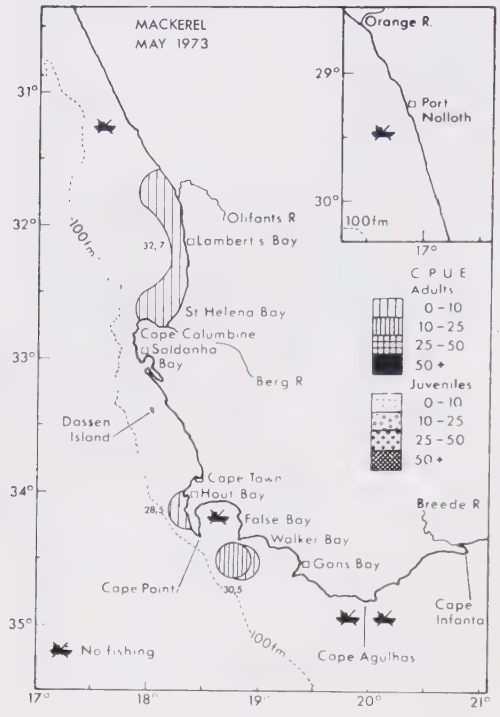
MACKEREL
MAY 1973
Orange R.
Port Nolloth
29°
30°
100fm
17°
31°
32°
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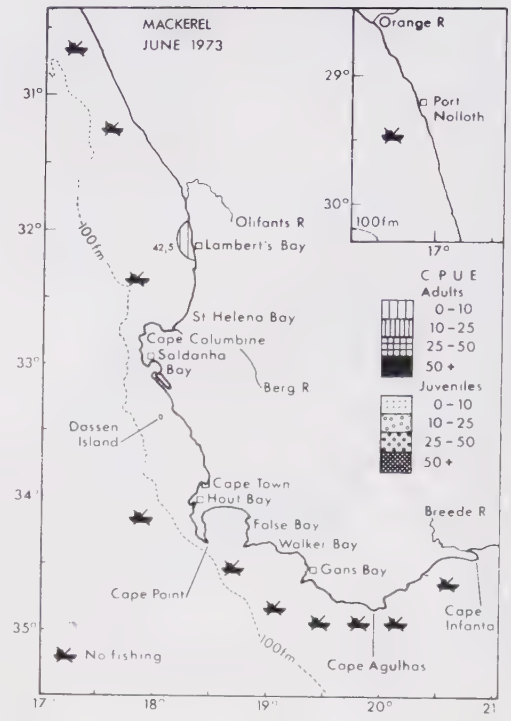
34°
35°
18°
19°
20°
21°
Olifants R
Lambert's Bay
32,7
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
28,3
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
30,5
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
JUNE 1973
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Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
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35°
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19°
20°
21°
Olifants R
Lambert's Bay
42,5
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
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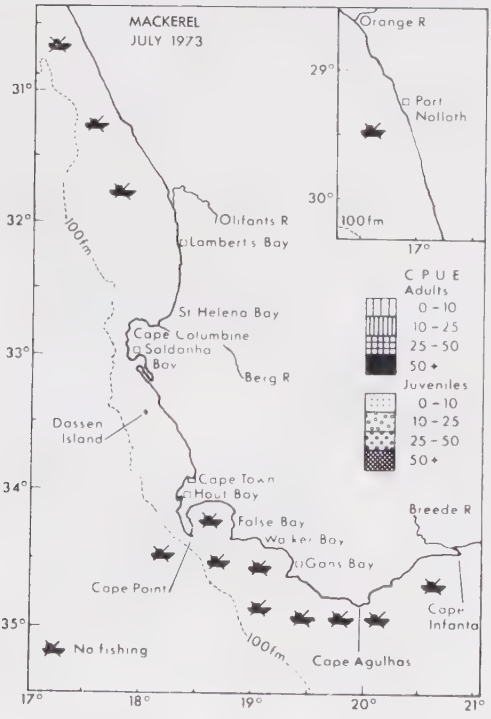
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
JULY 1973
Orange R
Port Nolloth
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100fm
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35°
18°
19°
20°
21°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
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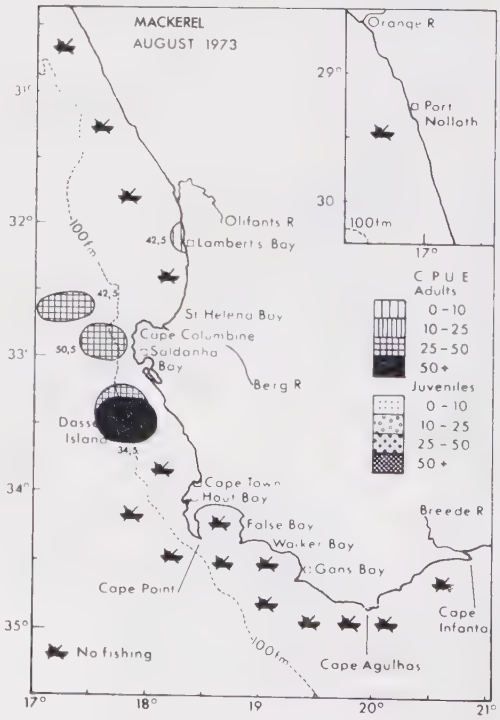
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
AUGUST 1973
Orange R
Port Nolloth
29°
30
100fm
17°
31°
32°
33°
34°
35°
18°
19
20°
21°
Olifants R
42,5
Lambert's Bay
42,5
St Helena Bay
Cape Columbine
50,5
Saldanha Bay
Berg R
Dassen Island
34,5
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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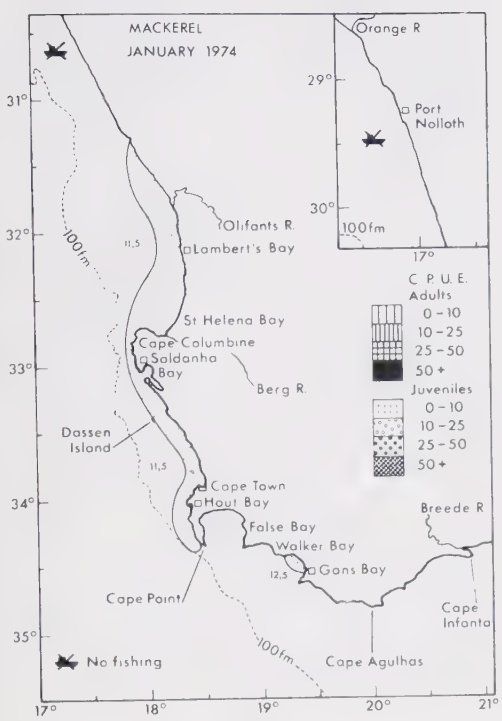
10 - 25
25 - 50
50 +


MACKEREL
JANUARY 1974
Orange R
Port Nolloth
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E.
Adults
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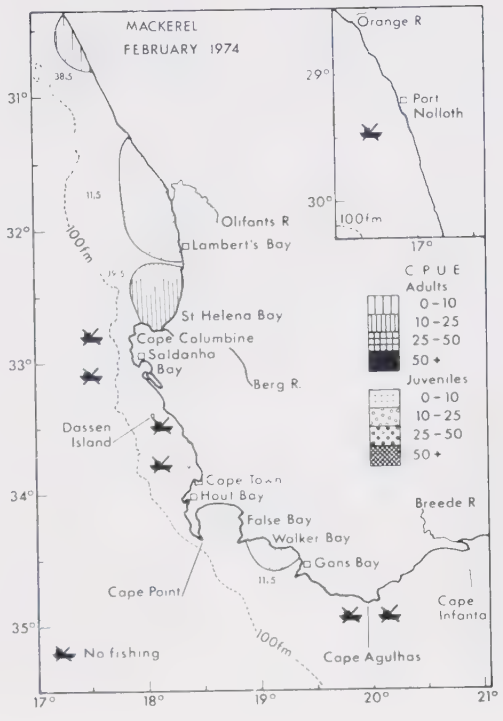
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
FEBRUARY 1974
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
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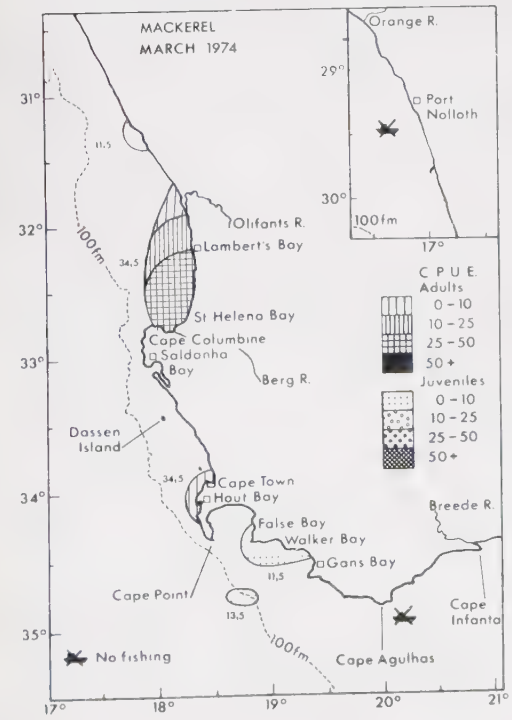
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
MARCH 1974
Orange R.
Port Nolloth
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E.
Adults
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10 - 25
25 - 50
50 +
Juveniles
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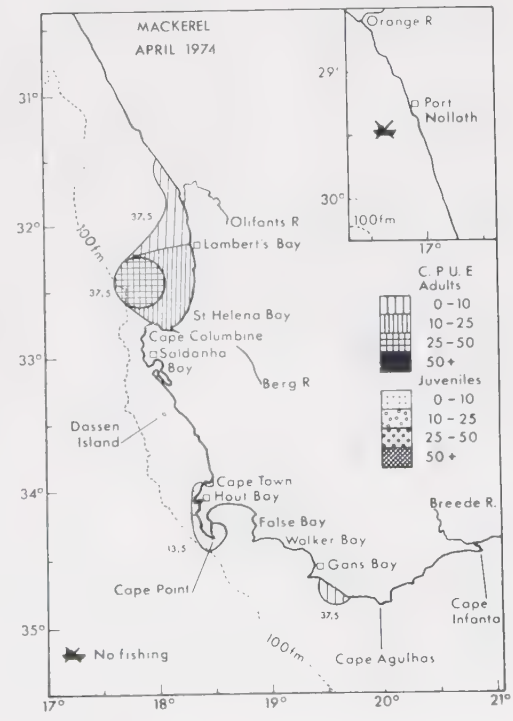
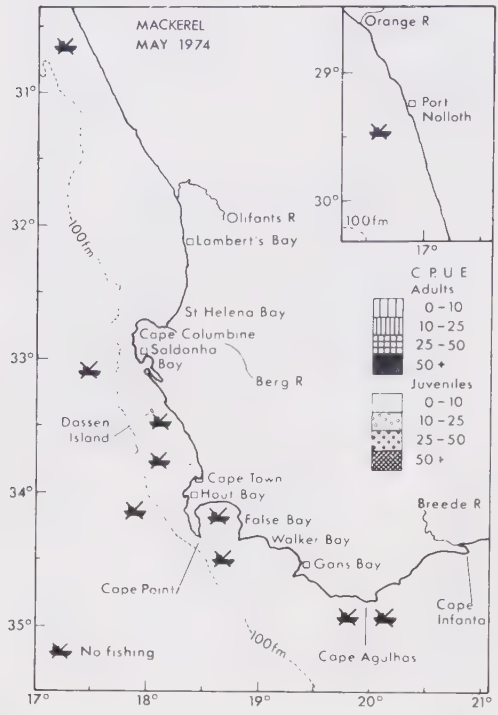
10 - 25
25 - 50
50 +


MACKEREL
APRIL 1974
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C. P U. E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


MACKEREL
MAY 1974
Orange R
Port Nolloth
29°
30°
100fm
17°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
31°
32°
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35°
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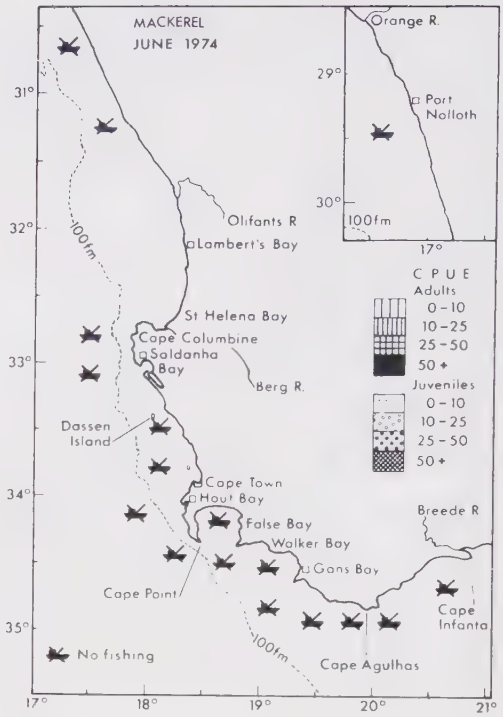
21°


MACKEREL
JUNE 1974
Orange R.
Port Nolloth
29°
30°
100fm
17°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
31°
32°
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35°
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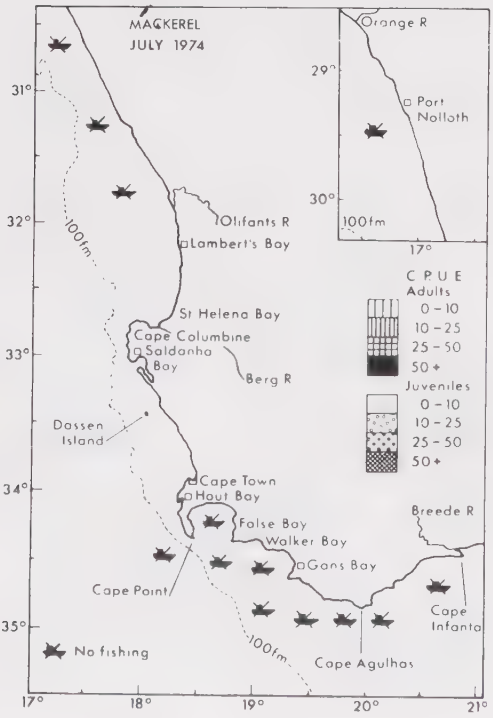
MACKEREL
JULY 1974
Orange R
Port Nolloth
29°
30°
100fm
17°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
31°
32°
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35°
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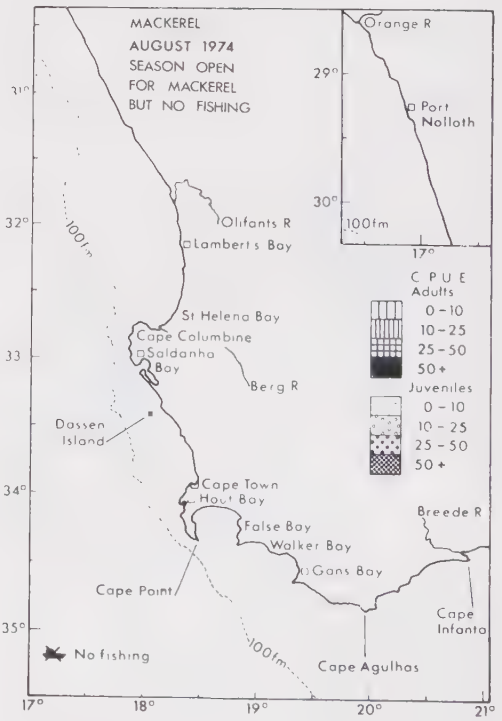
21°


MACKEREL
AUGUST 1974
SEASON OPEN
FOR MACKEREL
BUT NO FISHING
Orange R
Port Nolloth
29°
30°
100fm
17°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
32°
33
34°
35°
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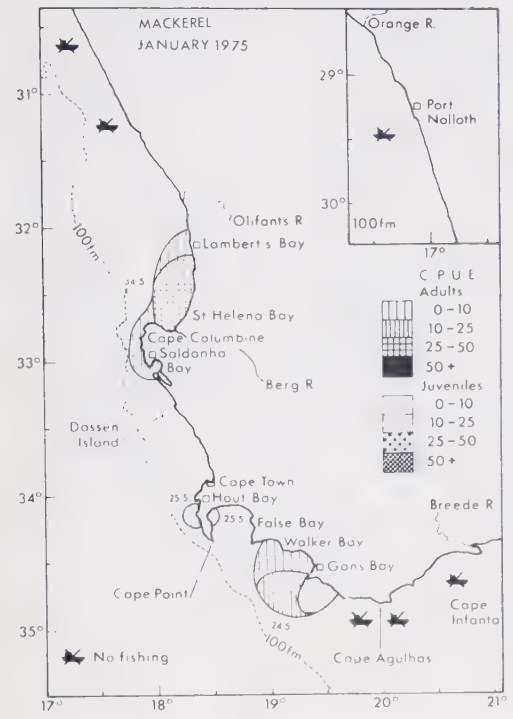
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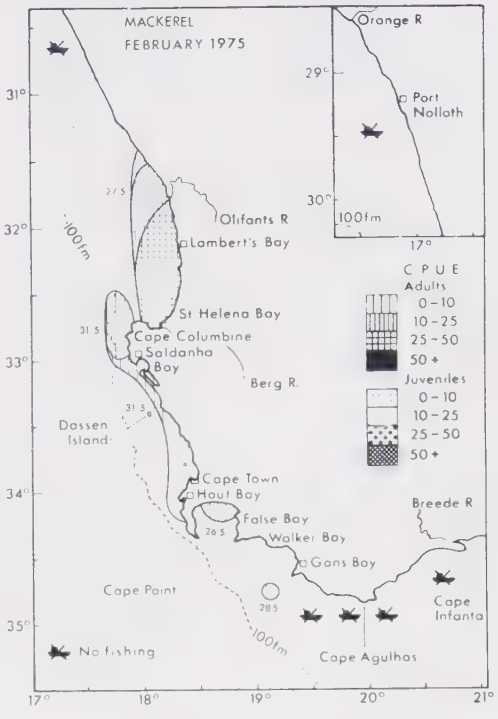
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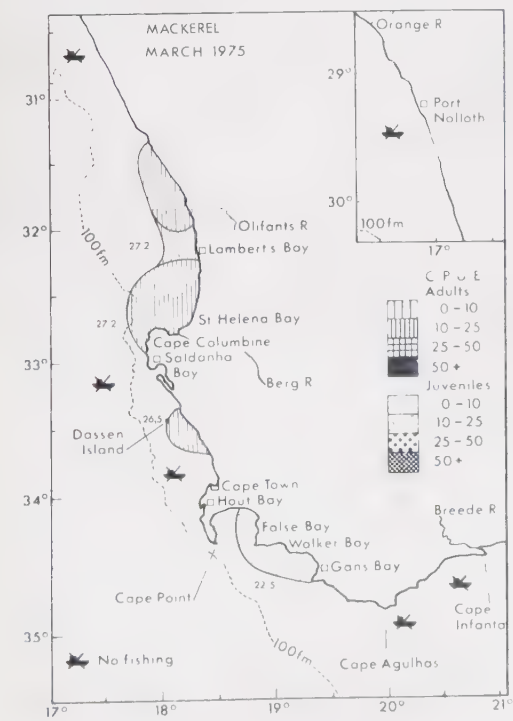
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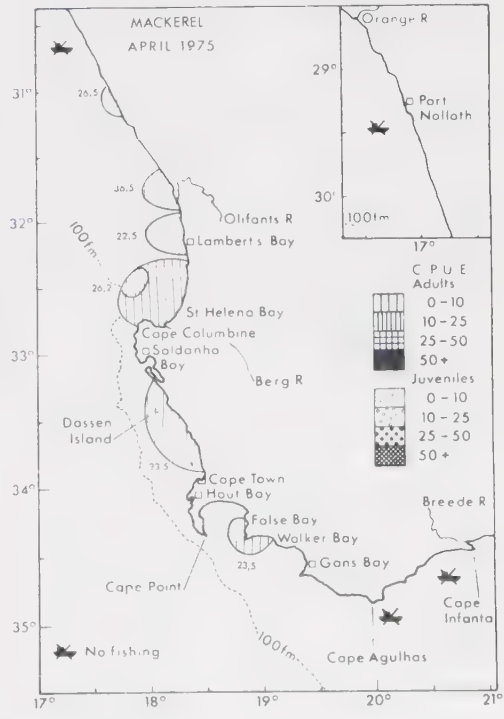
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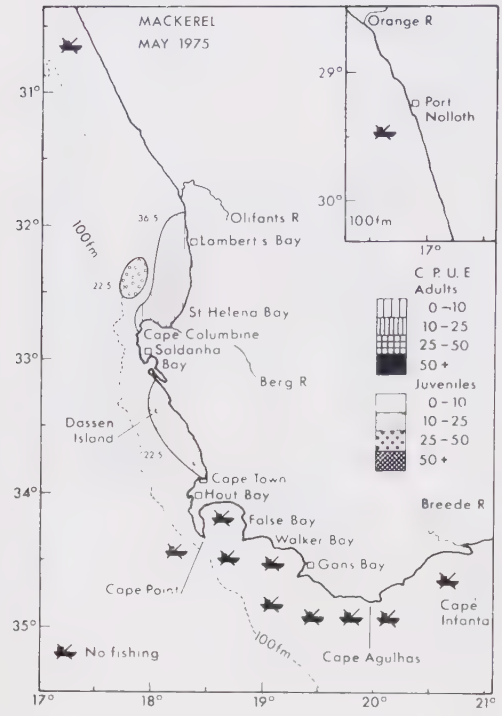
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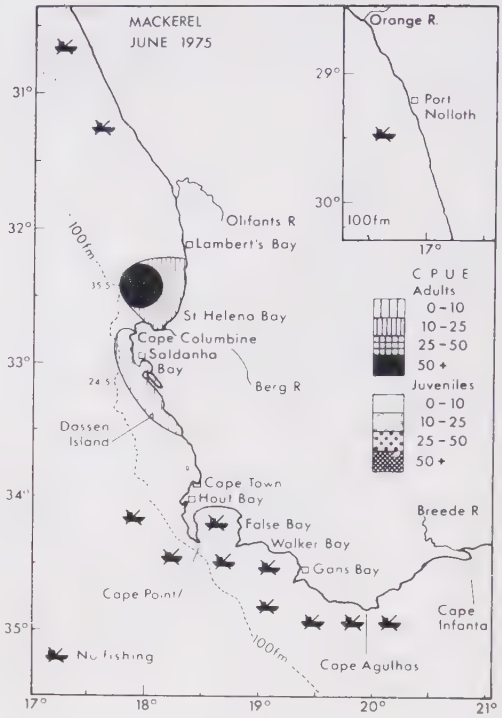
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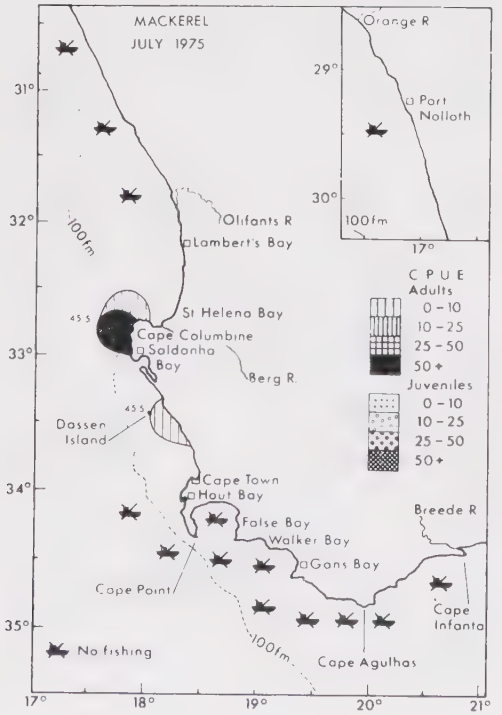
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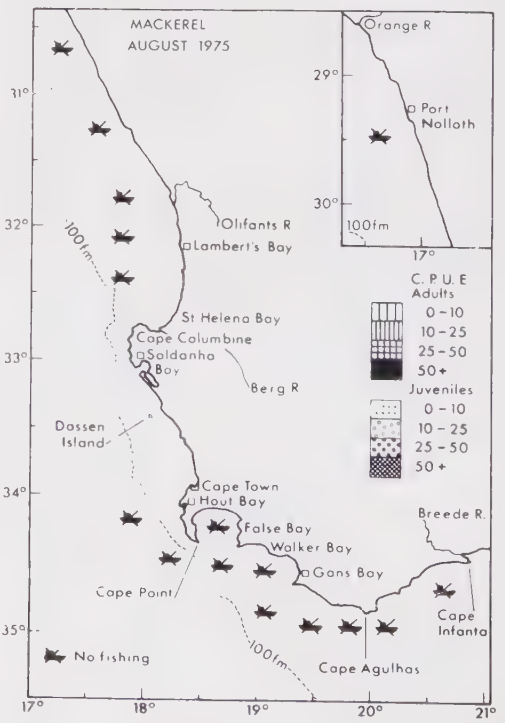
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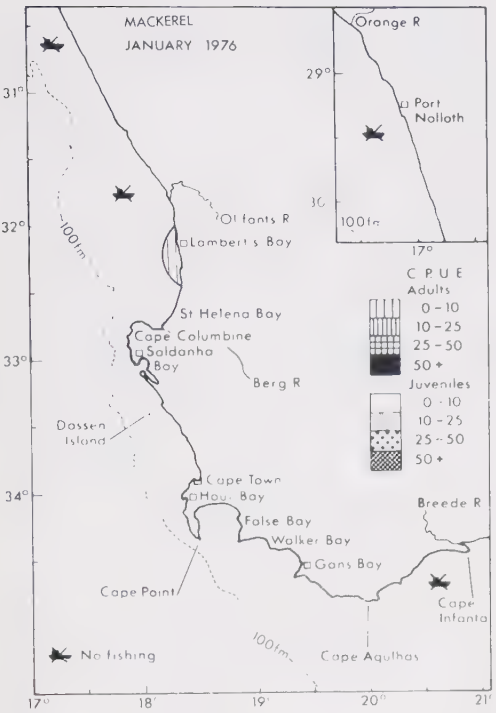
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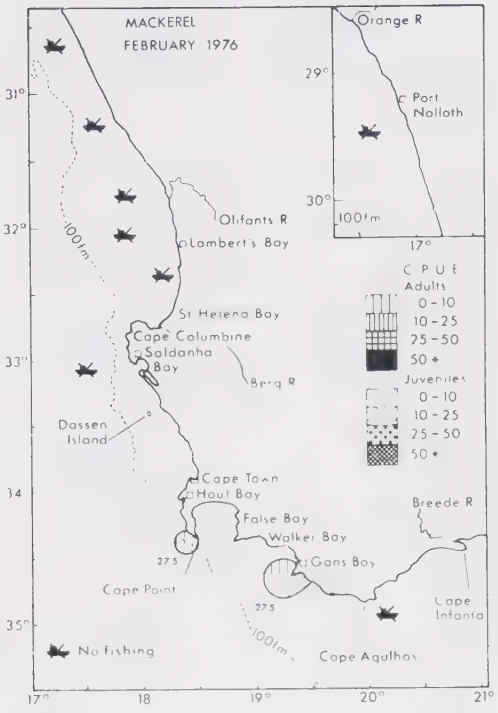
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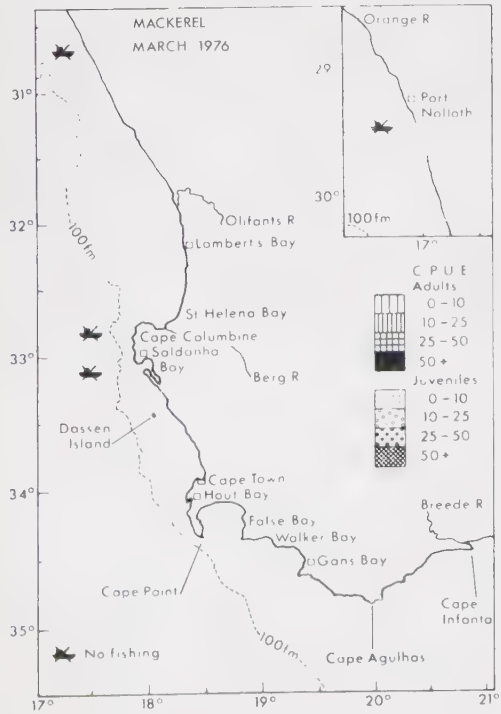
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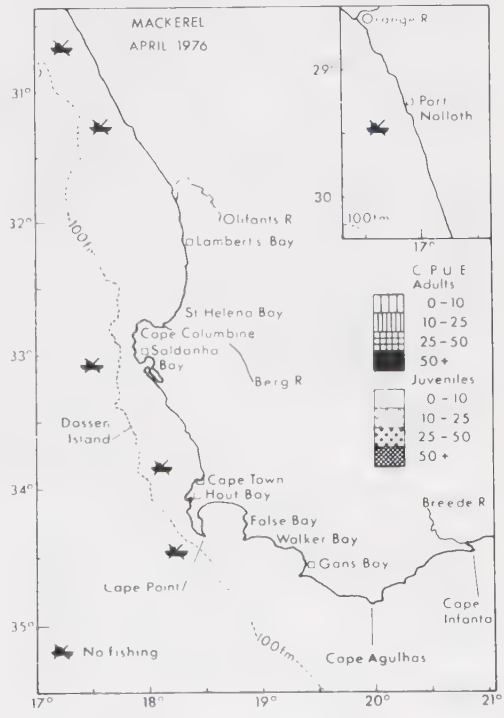
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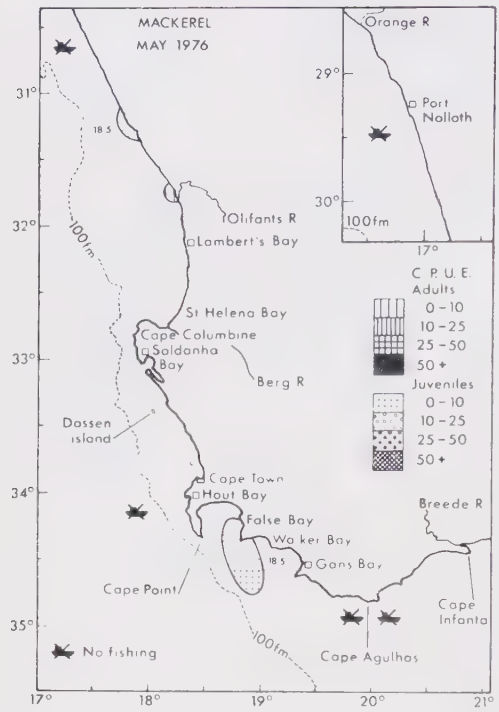
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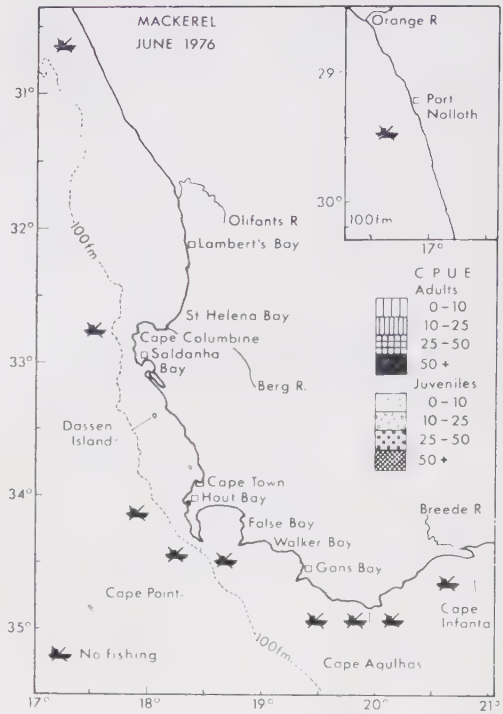
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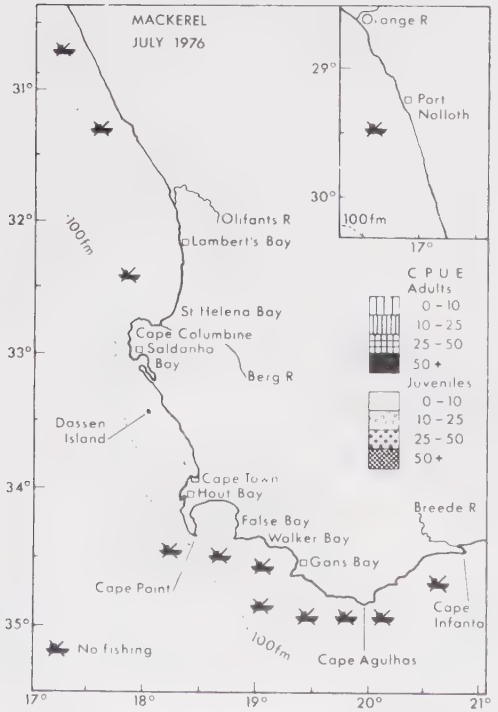
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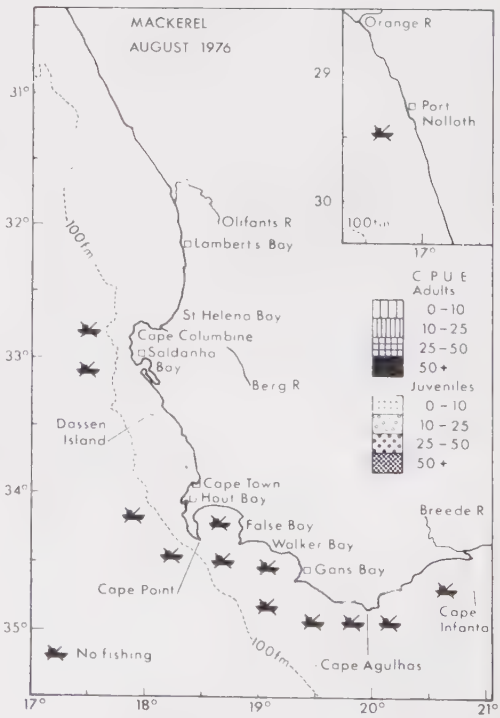
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